Global Change: from research to the classroom

An education for sustainability based on authentic science learning & project teaching: resources, methods, results and perspectives from European teachers and scientists

CarboSchools

What will you find in this book ?

Designed and written by a European team of teachers, scientists and science educators, this book primarily hopes to **inspire teachers to integrate authentic climate change science into their teaching**, based on the essential components learned through the CarboSchools experience:

- chapter 1 describes the critical role of education when responding to the climate crisis and the paramount need to **move Education for sustainable development from the margin to the centre** of school systems and curricula worldwide;
- chapter 2 gives practical ideas and examples of **how to design and run a school project** on the topic: how to organise student groups, how to assemble a coherent series of activities under a common issue towards an end-product, etc.;
- chapter 3 provides practical advice and case studies on the fundamental specificity of CarboSchools: **how to partner schools with scientists and research institutions**, and what this brings;
- chapter 4 offers **examples of experiments** illustrating the carbon cycle in the atmosphere, soils and oceans as an introduction to the CarboSchools library, where more than 25 experiments and field activities have been jointly tested and described by teachers and scientists;
- chapter 5 illustrates what we have learned through **in-depth evaluation** on the success of these activities with pupils and their actual educational impact.

This structure reflects one of the most stringent challenges of the Climate Change science educator: how to combine learning scientific facts in an exciting and efficient way – through inquiry-based learning – with fully addressing the meaning of this science to society – i.e. solving the climate problem and genuinely achieving sustainability. The first is essentially a matter of acquiring knowledge, where experiments (chapter 4) and teacher-scientist partnerships (chapter 3) will contribute in a novel way; the latter is rather a matter of working on values, representations and action competencies, where working within the broader frame of long-term interdisciplinary projects (chapter 2) will make a huge difference.

Most of these resources and findings derive from secondary school activities, but experience shows that many of them are also relevant to younger pupils, as well as to university students.

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www.carboschools.org

CarboSchools is funded by the 7th EU Framework Programme for research & technological development (Science in Society) and closely connected to EU research projects on carbon-related topics: CarboEurope and Carbo-Ocean in FP6 (2004-2009), EPOCA and GHG-Europe in FP7 (2008-2013)

Climate change brings economic, social and environmental challenges and opportunities. Citizens who have an understanding of climate science are more prepared to respond to both and are better equipped to take part in public debate on climate change. Informed by greater knowledge and understanding the decisions and actions they take in their personal and professional lives will make a stronger contribution to adaptation and mitigation.

Climate science is the chief source of knowledge and information – the content – that climate change education seeks to transmit. A reliable knowledge base is important for curriculum content and teaching/learning processes.

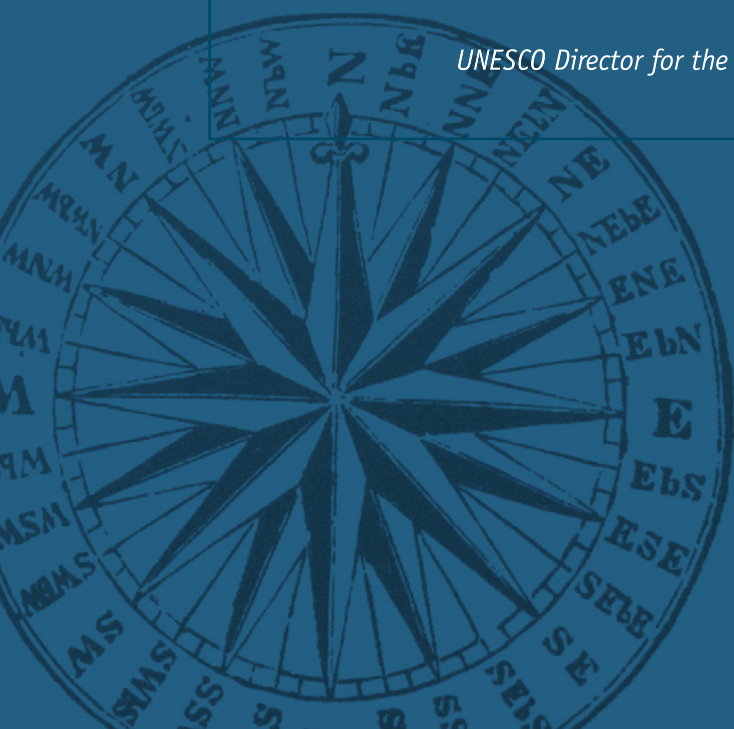
Initiated by European scientists and educators, the CarboSchools program is a unique attempt to bring authentic climate change science into the classroom, directly inspired by field research and located within the broader perspective of building sustainable societies. A wide variety of resources and methodologies have been tested and are now available for extensive use by teachers working to strengthen their approach towards this vital topic.

Climate change education can contribute to the relevance and quality of science teaching. The PISA 2006 assessment of scientific literacy among 15-year-old students concluded that strong performance in science and awareness of global environmental problems tend to go hand-in-hand, and both are associated with a sense of responsibility supporting sustainable environmental management.

As the lead agency of the UN Decade of Education for Sustainable Development (DESD 2005-2014) UNESCO endorses efforts in favour of education and awareness-raising on today's most pressing issue: sustainable development. While climate science is a crucial element of climate change education, this needs to be complemented with teaching about the social and economic dimensions of climate change.

I am convinced that this publication will help to enhance climate change education and encourage teachers to partner with scientists and researchers. Education is key to raising young people's awareness, developing their ability to adapt to a changing climate and to transforming unsustainable behaviours.

Mark Richmond
UNESCO Director for the Coordination of United Nations Priorities in Education



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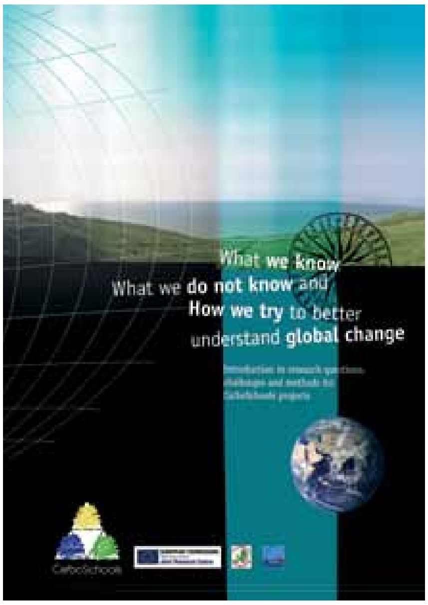
CarboSchools booklets for teachers (...and anyone interested)



(available in Dutch, English, French, German & Norwegian) gives an overview of the key questions science is facing to improve our knowledge of the Earth system and the way human activities disturb it. It explains how scientists collect and interpret findings from observations, experimentation and modelling, and how they do that in the frame of two large EU research projects, CarboEurope and CarboOcean - giving a particularly exciting example of how new knowledge is built through scientific research.

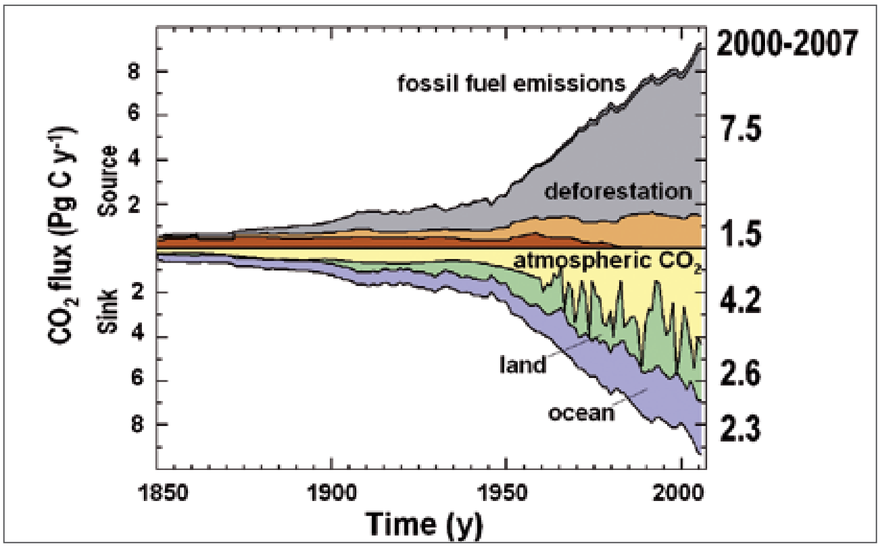
(available in English, French and Italian) summarises the key findings from 5 years of EU carbon research on land and ocean, and gives the wider picture of the human perturbation in the global carbon cycle. It gives an overview of the large-scale changes society has to implement to achieve sustainable development - i.e. where the atmosphere would no longer be a mega-dustbin for our CO_2 waste - and how scientists, schools and individuals may contribute. The booklet also features 6 examples of school projects from various countries.

Chapter 1

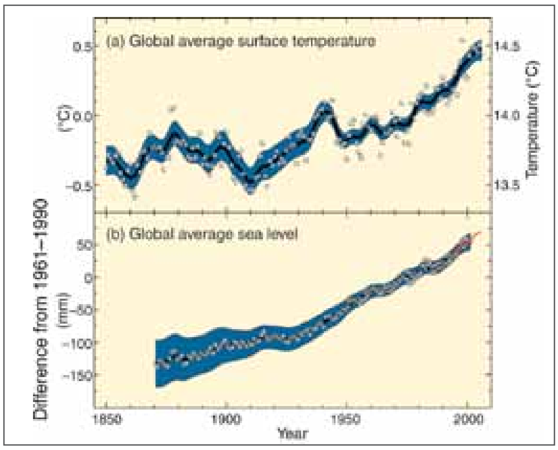
Learning about Global Change: from uncertainty and powerlessness to critical thinking and action

by Philippe Saugier, CarboSchools coordinator
Max Planck Institute for Biogeochemistry, Jena, Germany

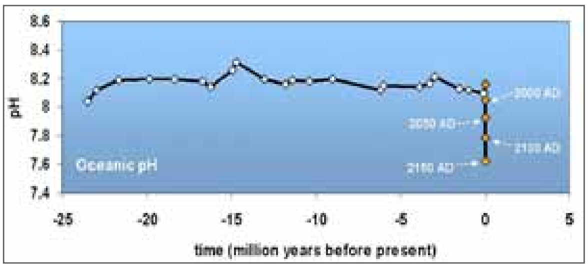
Climate change is the most blatant expression of the imbalance in people's relationships with others and with their environment, and one of the gravest threats to the pursuit of the human adventure on Earth. What is in danger is not the planet itself - whatever we do, it will always find a new balance over time - but the living conditions for a peaceful coexistence of billions of humans. This unprecedented global crisis calls for a tremendous educational effort aimed at understanding it, changing mindsets and ultimately restoring the balance.



Since 1800, by burning fossil fuel and cutting forests, we have released more than 400 billion tons of carbon - half of it during the last 30 years only (upper part of the graph). This extra CO_2 accumulates in the atmosphere, vergetation and ocean (lower part of the graph). (Global Carbon Project, 2008)



In the atmosphere, this changes the climate and increases temperature, which leads to sea-level rise and changes in precipitations (IPCC AR4, 2007)



In the ocean, the CO_2 acidifies the water at a rate and to a level not experienced by marine organisms for at least 20 million years. (Turley et al. 2006; Blackford & Gilbert 2007)

The challenge for society: achieving sustainable development

In 2010, global economic growth remains massively unsustainable. CO_2 emissions from fossil fuel burning and deforestation are still growing exponentially, thus presenting an increasing challenge to future generations to ensure their living: in the atmosphere, this extra CO_2 increases the natural greenhouse effect and changes the climate, reducing biodiversity and posing a threat to the lives of billions of people who might have to move or fight for water, land or housing, due to sea level rise and changes in precipitation combined with high population growth rates. In the ocean, the CO_2 invasion acidifies the water and threatens marine life, potentially affecting the whole food chain - all that at an unprecedented rate and speed.

Curbing such heavy trends is not a matter of making minor adjustments to mainstream pathways or reverting to the Stone Age, but of undergoing a whole change in paradigm and culture; a complete re-thinking of our production and consumption patterns and lifestyles. Ultimately, **a sustainable world means a zero-emissions world**, where use of non-renewable natural resources (e.g. coal and oil) has been replaced by use of renewable resources and where all waste is recycled. The current political goal of the EU (and several other groups) in international climate negotiations is to "stay below the 2-degree limit" – a level proposed as the threshold under which we could avoid "dangerous climate change". Model projections indicate that this requires a reduction of the world's greenhouse gas emissions to half of their 1990 levels by 2050. With a population of 9 billion (which we will probably reach by 2050), we will need to reduce emissions to about **2 tons per capita** to reach these levels, compared to currently more than 25 tons in the US or 10 in the EU.[2]

In other words: **drastic changes are needed, first and foremost in industrialised countries, but these have not yet occurred**. The debate is no longer "should we reduce our emissions?", but "how and at what pace?", and "do we start voluntarily now" or "do we wait until natural catastrophes or human conflicts do that for us at much higher costs?"

The challenge for education: from understanding to taking action

The emissions trends are not likely to go down before international agreements lead to ambitious policies combining incentives (taxes) and constraints (laws) on a global scale. But while governments are struggling with negotiations and policy, individuals can act

Climate scepticism: creating critical minds

Climate scepticism is sometimes worrying for public understanding, especially when the media give it excessive weight for audience purposes and hence confuse people with the scope of the uncertainties. But it is definitely interesting for education! Education is in no way about telling people what they should think and do - but about giving them the means and knowledge to develop their own thinking and form their own opinions and choices. Analysing diverging views on the degree of responsibility of human activities in the climate crisis and discussing these differences (e.g. through role-play) is a great learning experience.

When reading controversial articles, some pupils may easily be misled by spectacular headlines from frontline papers, such as, for example, „IPCC[3] was wrong". Teachers therefore have a crucial role to play in helping them reflect on what science and policy really mean. IPCC is neither right nor wrong, it just provides a regular synthesis of what science has found - and by its very nature, science is never right! What science does is to just try to describe and interpret what we see, and what is behind what we see. Everyday, new findings lead to new questions and sometimes they set doubts on previous beliefs. Thus, it is important to teach pupils that there is not much point in discussing the "truth" of a scientific statement, but instead to examine its reliability, its context and the underlying assumptions.

2) For more information on Climate Change facts and solutions, see the plethoric materials available on the internet - or the two previous CarboSchools booklets.
3) Intergovernmental Panel on Climate Change - the main authoritative source of scientific information for governments and policy-makers worldwide.

Just kowing is not sufficient!

One might think that when people get to know how polluting and harmful CO_2 is, they will start changing their behaviour. Things are of course far more subtle than that: personal choices and lifestyles are not primarily a matter of knowledge (e.g. knowing that tobacco kills is far from enough to prevent people from smoking). As all major curves are still exponential, learning the facts about climate change is terribly challenging for children and teenagers, at an age where they are shaping their vision of their place in society, public engagement, and relationship to the future. A worrisome sequence of events can be: asking „what can we do?", then feeling powerless or even guilty - and getting back to normal life and doing nothing.

Avoiding this sequence of events is clearly among the educator's highest priorities when addressing climate change science. We need children to leave school not only instructed about the problem, but also inspired, confident and challenged for finding new solutions. **Climate change education should therefore aim to progress from „awareness" to "understanding" and finally "taking action".**

immediately, and schools are undoubtedly one of the most critical links to families and young people. The empowerment of the individual is critical in driving the necessary behavioural change and pushing higher level institutions to move forward with policies, strategies and incentives for industry and society to transform.

One of the greatest challenges for schools in the 21st century is therefore to broadly prepare future citizens with the science they need for a sound and rational understanding of global change, and with the new way of thinking and skills they need to achieve sustainable development and to adapt to the changes already underway.

In this respect climate change education – i.e. an education for sustainability - should ideally integrate three pillars:

1) **content and knowledge:** understanding the facts, the scale of the challenge, the potential consequences, the solutions available and the governance strategies that can lead towards sustainable development pathways. This requires an interdisciplinary approach to science education, where a key challenge is to make science learning more exciting, more concrete, more experimental, and more connected to real-life problems.

2) **values and representations**: forging global citizenship and the feeling of belonging to one same planet and one same humanity. Understanding that it is not just nature and the planet which are affected, but the peaceful cohabitation of billions of humans. Reflecting on the historical responsibility of industrialised countries, the ethical questions raised in developing countries, the different meanings & implications of growth.

3) **action skills**: creating situations in which pupils experience the democratic process of thinking up, agreeing, implementing and evaluating concrete changes at the individual and collective levels. Giving pupils a positive experience of that sort is of critical value for their future role as active members of society.

The last two pillars are particularly challenging for schools, which are traditionally (with variations depending on countries) less prepared to work on values, behaviour and skills than on transmitting knowledge and facts. Timetable, curricula & disciplinary constraints are major obstacles to this in most school systems: it is all not just a matter of new contents, but also of cultural and structural changes.

From the margins to the centre - now!

Educational systems all over the world thus face this tremendous challenge: preparing future generations to transform our societies from the heavily carbon-addicted and waste-producing world we inherited towards a genuinely sustainable society no longer jeopardizing the capacity of the next generations to live together and respond to their needs.

This is at the core of Education for Sustainable Development (ESD). Largely grounded on the experience accumulated since the 70's in environmental education, it integrates other historical currents for educational innovation, such as peace education, health &

World Conference on Education for Sustainable Development: towards an "IPESD"?

The paramount importance of ESD was emphasized by the UN World Conference on Education for Sustainable Development in 2009 in Bonn, Germany[4], where participants discussing climate change issues stressed the urgency for **large-scale investments for a transformative education**, i.e. a critical values-based, integrated participatory education which enables empowered citizens to move from learning the facts towards taking action; and this not in the margins, but in the centre of daily educational practices everywhere in the world. The conference also questioned the absence of education in the agenda of international climate negotiations and urged UNESCO to prioritise the development of a global strategy for ESD. Further statements mentioned that:

- The conceptual framework for ESD is mature and we now need to put this knowledge into action.
- Despite huge progress in many countries ESD is still in its infancy.
- ESD often confronts pupils with contradictions between values & knowledge and the daily school reality.
- Mainstreaming ESD requires massive investments into human resources and buildings for which no large-scale funding instrument exists so far.

As a prospective idea within the Climate Change workshop this stimulated the vision of an „Intergovernmental Panel on ESD" - the educational counterpart of IPCC - i.e. an instrument that would be dedicated to accelerating the training of future citizens in sustainability all over the world, by setting-up the necessary means for educational research & training and corresponding financial instruments at the national and international levels - such as using part of the foreseen revenue from future carbon taxation & trading for investments into ESD.

HIV/Aids education, development education etc., in an attempt to address all aspects of sustainability.

Nevertheless, despite huge progress ESD is still often seen as a side activity within the hands of a few passionate teachers out of normal school hours. **It is high time to make it a core component of formal education**, as climate change curves show how much we are moving further away from sustainability every day.

Climate change is one of the messiest problems mankind has ever encountered - there is no certainty about the consequences of the decisions we make (or do not make) today; there are no existing solutions available that are just waiting to be implemented; there is no existing authority that can take the lead and tell people what they should do. However, it is also the greatest opportunity that has ever arisen to supplant national, economic and identity-based interests and to build the mechanisms of solidarity and world governance which humanity needs, not only to preserve the environment on which it depends, but also to contain its violence and the domination of private interests. There is a long and chaotic way to go, but sooner or later the imperative of survival will compel us to come up with new forms of global regulation capable of restoring the balance.

Beyond scientific understanding, extricating ourselves from the climate impasse is therefore more than anything else a matter of world governance - and we will not build true world governance without global citizenship. In a country like France, education forged the national consciousness and identity in the nineteenth and twentieth centuries. Education must now forge our global consciousness and identity as responsible inhabitants of the Earth. In the 21st century, the essentials are now to learn how to read, write and count - and also how to live together in peace among 9 billion humans on our one, unique and fragile planet.

The CarboSchools contribution

CarboSchools is a tiny drop in the ocean of initiatives to elevate ESD to the scale of the climate challenge. It started in March 2005 as a call launched by a group of scientists and educators gathered in Sainte Croix (France) by CarboEurope and CarboOcean, two leading EU research projects investigating the carbon cycle on land and ocean respectively, who felt that "they not only have a contractual, but a moral obligation to contribute the results of this research to the public discussion on global change".

4) See the Bonn declaration at http://www.esd-world-conference-2009.org/fileadmin/download/ESD2009_BonnDeclaration080409.pdf

Following this call, a growing number of school projects flourished in several of the ca. 100 research institutes involved, leading to inspiring presentations during annual science meetings. In 2007, a field-tested concept, a first set of resources and an enthusiastic human network gave confidence and institutional support to submit a more ambitious proposal to the Science in Society programme of the EU. From 2008 to 2010, nine institutes joined this initiative to „make science learning more engaging and challenging for young people as future workers, consumers and citizens", and in response to the growing decrease in the number of pupils choosing scientific studies. This book is the final publication of this project cycle.

Pupils at the "street art" workshop of the CarboSchools Spring School present their drawings to the local press

The basic idea of CarboSchools is to promote direct partnerships between secondary school teachers and global change scientists for young people to learn about climate change, gain a positive experience of scientific research and act locally to reduce emissions of greenhouse gases. The two main goals are (i) to stimulate students' interest for science & scientific studies and (ii) to equip them with basic understanding of this major scientific challenge and its interaction with society.

The strength of partnership projects is that pupils get involved in a process over several weeks or months, or even years, built on a direct relationship between scientists and teachers, thus enabling them to gain practical experience of research. The stakes here are no longer only to inform or transfer knowledge, but also to encourage questioning among young people and to increase their desire for understanding and their will to build a future which will enable us to manage the challenge of global change, in an attempt to address the three climate change education pillars mentioned above.

Partnership projects can feature different activities, such as real-time experiments (in the lab or field, or at school), site visits, lectures, debates, access to research results, communication by e-mail, etc. A final output, such as an article, an exhibition, a conference, a webpage, a set of measurements and their interpretation, concludes the students' work by sharing the findings with a wider audience (parents, friends, local community, city...).

Thus, in contrast to many climate change education projects essentially based on delivering information via the internet, CarboSchools is first and foremost based on human contact and on placing scientific issues in their wider social and citizenship context. Young people are overwhelmed with information about climate change, but not with offers of meaningful activities in their school education, or with personal connections with real scientists working on a topic which remains fascinating and tremendously concerning, and graphically illustrates first-hand the uncertainty of science.

School science is often perceived as boring, theoretical, disconnected from social issues and real life and not related to real science. Climate change research, on the other hand, is highly international, systemic, interdisciplinary and full of unknowns investigated by passionate people in often remote, exotic areas; it influences decision-making more and more at every political and economical level, directly impacting everyone's daily life; it is exceptionally popular as a science topic in the press and on TV. Building on this contrast CarboSchools connects school education with authentic scientific learning based upon:

- questioning and experimenting, rather than on transmitting pure knowledge,

- addressing a complex issue that affects all of society,

- developing close personal contact with researchers to discover how they work to challenge the stereotype and see scientists as real people.

Since the institutions which developed CarboSchools focus on research in geosciences, the topics covered mostly deal with understanding the climate system, its components and its mechanisms. Except for geoengineering approaches, geoscience institutes do not study approaches to prevent or mitigate climate change, which explains why most resources and activities developed in CarboSchools do not cover many of these key aspects. However, given the persisting debate on the reality of climate change, our prime concern was to equip the pupils with facts, insights and a deeper understanding to engage in this debate.

The legacy of the project for the teaching community

Thanks to the endless encouragement and support by CarboSchools' regional coordinators appointed in each of the nine partner institutes, a total of about 2500 pupils, 230 teachers and 220 scientists took part in this experience from 2008 to 2010, with a great variety of approaches and projects of all topics, ages, duration, etc. The vitality of the project reached its climax at the Global Change Science Festival in April 2010, which gathered more than 100 pupils, teachers & scientists representing schools from all over Europe. Experiments, posters, movies, presentations & theater plays invaded the hall and auditorium of the Max Planck Institute for Biogeochemistry in Jena, Germany, within an incredible atmosphere of sharing experience and project ideas. Teacher training and networking proved to be essential success factors; teachers were involved in all steps and in project meetings both locally and at the European level, creating a community of practice and a platform for cooperation, without which the project would never have grown to such an extent.

All these projects, and the European co-operation among them, constituted a probably unprecedented educational laboratory where innovative tools & methods have been tested and systematised, and which are now available to many more schools outside the initial nucleus of participants. These resources are all publicly available in the on-line library of the www.carboschools.org website. This book attempts to illustrate their value, their relevance and their context, in the hope to see them widely used, translated and further improved.

Key-facts about CarboSchools

CarboSchools was initiated by CarboEurope and CarboOcean, two major EU research projects on the carbon cycle, later joined by EPOCA, investigating ocean acidification and GHG-Europe, investigating greenhouse gases on the European continent.

Pilot phase 2004-2008

- ~90k€ funding from CarboEurope & CarboOcean + ~260k€ funding from Socrates/Comenius for a teacher training project coordinated by the University of Education Heidelberg
- several partnership projects active in Denmark, Finland, France, Germany, Holland, Italy, Norway, Poland, Spain and Sweden
- main outputs: a first website, two booklets in various languages, short & full versions of a Teacher-Scientist Partnership guide

Development phase 2008-2010

- 980k€ funding from the EU Science in Society programme
- 2500 pupils, 230 teachers and 220 scientists directly involved in partnership projects
- regional coordinators in 9 institutes to support teachers & scientists engaged in projects (in France, Germany, Italy, the Netherlands, Norway, Spain and the UK + associated partner in Romania)
- intensive cooperation between regional projects through project meetings, phone conferences & regular communication
- „schoolCO2web" measurement activity gathering data from CO_2 sensors & weather stations
- evaluation study by educational researchers on the impact of the projects on students
- main outputs: new website with fully tested materials for hands-on experiments & project activities, evaluation materials & reports.

Chapter 2

Project ideas and methodology

by Vibeke Birkmann
Greve Gymnasium, Denmark

One of the aims of science education is to give students an insight into the complex world we live in, and to enhance their action competencies in their own lives as citizens in a globalised world. To understand the many aspects of climate change, students must understand that there is a very close interaction between scientific processes and the interest of society, and that to study these changes they must use methods and theories from the natural sciences, as well as from humanities and the social sciences. One of the aims must also be to enable students to reflect on the challenges of climate change - be they manmade or due to natural causes - in a responsible way.

This chapter gives some suggestions of how to use interdisciplinary projects as a way to teach climate change and sustainability. It outlines how different projects can be planned, completed and assessed, with an emphasis on multidisciplinary projects.

The planning phase

How many subjects should be involved?

Depending on student age and the subjects studied, you could choose two or three subjects as the basis for your project. However, you should bear in mind that it is not always easy for two or more teachers to find time to plan together. With younger pupils, it might be a good idea to introduce project work in one subject, so that they gradually adapt to this way of working; but as soon as they are familiar and comfortable with it, interdisciplinary work can be introduced.

What subjects should be chosen?

The combination of subjects will depend on the local curriculum, but when working on climate related topics the following combinations are usually successful: biology, maths and social sciences or geography, economics and mother tongue language or physics, chemistry and history. If the project has an international aspect to it, you can include a foreign language subject, a perfect opportunity for pupils to develop their language skills via authentic use. (For an elaboration of this see the example from Max Linder School in France – appendix A).

How to choose a project topic?

It is important to involve the students as much as possible in each stage of the project, including the planning, so that the students actually feel ownership, and thus responsibility, for the work being done. 16 to 18-year-old students should be able to come up with their own suggestions for the precise problem they want to work on; the overall topic being in accordance with their curriculum. For younger pupils, the teachers should suggest the actual problem to be studied.

What preparations are necessary?

Before the actual project phase, it may be necessary to provide sufficient background knowledge, so that the pupils can communicate with each other, as well as with scientists, politicians, farmers and other resource people in an informed way. This common knowledge can most easily be acquired through ordinary classroom lessons based on textbooks or perhaps internet studies.

Setting up a common platform or wiki, for instance on the school intranet, where all documents can be saved, can also prove to be time saving. At the same time, it gives the teacher a possibility to follow the process while the students work.

Teachers may feel that the pre-project preparation phase is quite time consuming, because - especially with young pupils - everything should be thought through, field trips should be planned in advance and so on. However, once the project has started, most of the preparation will have been completed; so in reality there will just be an intensive pre-project phase and a more relaxed phase the project itself is going on. When working with more mature students who have tried project work before, the challenge for the teacher may actually be to let go, and trust that the students can plan their own time and make their own arrangements with scientists and other partners.

It is also important to address the issue of many teachers being used to working on their own: one teacher, one class, one subject. Without actually being control freaks, many teachers are used to being solely responsible for the outcome of classroom activities, and it can be difficult to let go of the responsibility without quite knowing what the end result will be. Schools that want to encourage project work where none has been done before should set aside resources so that there will be enough time to plan and evaluate the projects. Anyway, remember to keep it simple in the beginning. Two subjects and one visit to a research site and a simple report from the students is a good starting point. If too many different inputs are used, the pupils, as well as the teacher, may lose sight of the general idea and goal.

How long should a project last?

This depends on many factors, such as student age, the number of subjects involved, school curriculum, the number of external contacts, such as lectures by scientists or field excursions, and the expected outcome, e.g. a report, a peer presentation or a newspaper article. In the examples described below, and in the appendices, it is possible to see the duration of various projects.

Measuring soil respiration

How should groups be formed?

The pupils need to feel comfortable working together. Ideally, the students should form their own groups and work together in perfect harmony; but all teachers know that this is not always the case. Maybe the students who want to work together are such good friends that they spend more time having fun together than actually working, or maybe some pupils will be left out because nobody wants them in their group. (For an elaboration of this point, please refer to the example from Max Linder School, France – Appendix B). It is therefore necessary for the teacher to organize this process. There is no best way. Each class has its own dynamics that should be taken into consideration when the groups are set up.

Some examples of how to form groups:

- Students form their own groups and choose their own topic (within the general framework, of course)
- Various topics are defined, and students then choose the topic they want to work on, and groups are formed accordingly.
- The teachers form the groups by drawing lots
- The teachers form the groups according to the students abilities – this could mean either that groups should be formed by students with the same skills or the exact opposite

But no matter how it is done, it will be almost impossible to avoid one or two groups being composed of individuals that initially do not cooperate very well. Therefore, it might be a good idea to discuss group dynamics with the students. If they have already worked in

(continued p. 16)

Example 1: a simple "beginners' project"

Title: Greenhouse effect
Subjects: Biology and social sciences (geography)
Duration 10 lessons, 50 minutes each

Background knowledge required, studied in lessons before the project period:
- Biology: C-cycle, photosynthesis, respiration, greenhouse gas
- Social sciences: The need for energy in an industrialised world, fossil fuels and world trade, land use

Project breakdown:
Lessons 1 – 2: Students work in small groups of 4. Each group chooses one out of three topics within the overall subject: e.g. consequences for agriculture, consequences for global fossil fuel trade or sustainable energy sources. The groups prepare questions to researchers before the excursion.

Lessons 3 – 5: Visit to research laboratory. Demonstration of CO_2 measurements. The various groups meet scientists and get the possibility to ask their questions.

Lessons 6 – 8: Groups prepare power point presentations for each other. It is important to tell the groups that they must clearly demonstrate in what way the two different subjects (in this example, biology & social science) can contribute to shedding light on their chosen topic.

Lessons 9 - 10: Presentations and evaluation. Evaluation should comprise a peer discussion, as well as a formal evaluation from the teachers.

After the project, the whole process should be evaluated by teachers and students together.

Example 2: a more advanced project including more subjects, but the questions are set and the task is defined by the teachers.

Topic: "An Inconvenient Truth", a film by Al Gore, former US vice president
Subjects: Biology, geography, English, history, rhetoric, media studies
Duration: One week

Set problem: Make a presentation and evaluation of "An Inconvenient Truth". Your report must be one coherent presentation in which you include discussions of the following points:
- What artistic effects are being used in the film to underline Al Gore's point of view?
- Discuss the scientific focus of the film. Are all the consequences presented scientifically sound, and is anything left out?
- Give an account of the rhetorical patterns of speech used in the film
- Give an analysis of the film and genre to which the film belongs
- How are the basic values of the American society reflected in the film?
- Give an analysis of the relationship between facts and beliefs in the film

Example 3: free project within a given framework: A changing world – man and nature

Duration: 6 weeks from the day when the students are given the assignment until they hand in the written synopsis. 7 school days within this period are free for the work on the project. After this period the oral presentation is scheduled for the examination in June.

Choose two or three subjects, but remember that they must be chosen so that they not only represent science, but also social sciences and/or humanities

To obtain a good mark in this project students are required to hand in a synopsis of 4 – 5 pages that they can use as the basis for an oral exam presentation. This presentation should give an in-depth and scientific discussion of the chosen topic, as well as demonstrate that the student
- is able to use and combine methods from more than one subject when dealing with a topical problem;
- is competent in identifying and discussing the contributions and limitations of the various subjects and the methods used in this survey;
- has developed skills in using knowledge from more than one subject to evaluate complex problems.

Students work in groups of two.

Example of a past project:

One group chose: "Bio fuels – a sustainable solution to world energy problems?" using the subjects biology, chemistry and history (social studies)

Besides carrying out extensive reading, they visited two universities where, under the guidance of scientists and university students, they experimented with the production of bioethanol from various products such as sugar, straw, cotton and duckweed (Lemna). These experiments formed the starting point for a survey.

groups on projects lasting 3 or 4 weeks, then this will not be necessary, but otherwise it can be very productive to discuss how a group of four students can share the work. One person is the group leader, another is the secretary, etc. And the roles can change during the course of the group work. It is also important to emphasize that each individual is responsible for the well-being of the whole group, and if a person has not done the task that was agreed upon at the last group meeting, then the whole group, and not just the individual, will suffer accordingly.

If the creation of long term groups causes too many problems, another solution could be to work in matrix groups. In this way of working you first form, for example, 5 groups of 5 students each. Each group studies its own area within the common context and the students of a group become "experts" in their field. Next you form five new groups each consisting of one student from each of the original five groups. In this way, each new group comprises all the expertise acquired in the first part, and the groups can thus pool all their knowledge, perhaps making different forms of presentation e.g a power point presentation, a newspaper article, a newsletter to the school, a questionnaire and its results, or eco poems.

Getting started

Once the groups are formed, within the overall project's topic the groups must (for young students with the help of the teachers) find a problem – a seemingly paradoxical statement or a question, such as "Is it possible to produce biofuels to cover our need for energy in a sustainable way?"

The next step is to identify sub questions that must be examined in order to answer the main question, and to set out what subjects, methods, experiments, interviews, written information, etc. is needed in order to answer the sub questions. To ensure maximum interest from students it is important to - whenever possible - make them feel that they are not only reproducing facts that have been studied thousands of times before, but that they are actually making a first hand investigation – authentic learning.

On this basis groups can then carefully discuss their needs for resources such as:

- Literature, articles, books, internet- based information
- Experiments
- Out-of-the-classroom-contacts (scientists, industries, farmers, politicians etc.)
- Information on the people that will see, read, hear the project
- Knowledge of the skills needed to write a formal report, make a power point presentation, etc.

It's a good idea to start looking into this a couple of weeks before the full project period, so that everything is ready when the actual work starts.

Process or product?

One of the key steps when starting your project is also to discuss what the end products are going to be. This can be a formal project report, but it can also take many other forms (see box), and it should be kept in mind when planning the project. (To see an example of how such project work can be set up and evaluated using portfolio work, please look at the example from Isarnho-Schule, Germany – Appendix C).

In this respect, it is very important to decide whether the focus of the project is rather the process or the product. If the project is process oriented, the emphasis can be on learning to work in groups, interdisciplinary work, working with scientists, field trips, finding information on a given topic and so on. It is often a good idea to introduce students to this way of learning by making short term projects that focus on some particular steps, but at the same time it is important to have a good topic that really interests the students.

When the students are familiar with these "tools" then they will be able to focus more on the product which can take many forms, such as reports, newspaper articles, small videos, power point presentations, demonstrations for parents or the public or peer education. It is often possible to combine two or more of these products, and if the students participate in international projects such as CarboSchools or Young Reporters for the Environment it is possible to have a language as well as a scientific focus. Lessons in the mother tongue can be used to discuss how to write a coherent report or article, in which the conclusion actually corresponds to the problems set out in the introduction and the reader's attention is caught from the beginning.

Evaluation

If the project is integrated into the curriculum, the marks for the end products will contribute to the overall year mark (how this can be done, and the exam requirements, vary a lot from one country to another) and a written test may help the students to demonstrate what they have actually learned.

Remember to set some time aside for the evaluation of the process. It is vital to get individual and group feed-back from the pupils in order to assess the project and gather suggestions for how to work the next time. What went well and what were the obstacles? Should more time be assigned to the group process next time? Did the students understand the presentation from the scientist? If the final product involves some kind of peer presentation, make sure that it is evaluated; peer evaluation is a very valuable tool.

Getting teachers and school management interested

For teachers, one of the greatest bonuses of this kind of classroom work is the cooperation and inspiration you get from working with other teachers, with the reward of seeing the concentrated work students are

Experimenting solar energy

Examples of end products other than a project report or an oral presentation

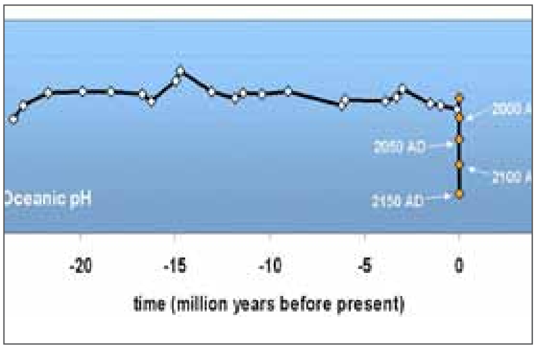
- Invite local politicians to a hearing
- Set up your own wiki or webpage
- Short term exchange visit (e.g. 2 days) to/from other countries or other parts of your own country, where the students present their products
- Newspaper article to "Young Reporters for the Environment"
- Establish a school policy on sustainability
- Write a "letter to the editor" for a local newspaper
- Write eco-poems
- Invite local primary schools to try out various board games or experiments produced and set up by students
- Make a video for youtube
- Run a competition between classes to find out who can come up with the best ideas for saving energy (being sustainable) and actually put these ideas into practice
- Hold an energy-saving party at school (organic food cooked by solar energy, unplugged music, light generated by bicycles that students pedal, no disposable plates, etc.)
- Form your own expert panels and invite parents for an educational evening
- Produce your own bioethanol

actually able to give to a project which they really feel is their own.

As mentioned above, the best way to motivate teachers is to set aside some extra resources or funding for this kind of work; but it is also important to remember that hearing about successful projects from others and a platform where ideas and finished lesson plans can be found, often serve as the greatest inspiration.

Common obstacles to project work are time and money. The way to convince school management and administrations to set aside time and money for project work will depend very much on the schools and country involved. It is always better to be a group of teachers than just one, because this will enable you to assure the school management that the time and money spent on the project will actually give results that will have a widespread effect in the school.

A successful application will typically demonstrate how the proposed project will address part of the school targets and values and how it will give the school good public relations and favourable local publicity. If possible find a national or international project and apply to participate. Via such projects you can get in contact with other teachers who work on the same topics, thus increasing the possibility of collaborating and sharing ideas.



Case Study 1:

Integrating a climate change project into the school curriculum and a multidisciplinary program Lycée Max Linder, Libourne, France

by Mauricette Mesguich and Stephanie Hayes

Climate change is a complex subject in which science, economics and citizenship are inter-related and cannot be studied independently without being incomplete or incorrect. Therefore, at Max Linder School, pupils work on climate change by combining these three complimentary aspects within a project that is integrated into the curriculum and a multidisciplinary program.

How is it done?

The team of teachers comprises six voluntary teachers from different disciplines, who incorporate climate change into their teaching program. In the team there is a core teacher who gathers and unites all the work from the different subjects.

One of the innovative aspects of this way of working is that two teachers from two different disciplines teach one class together. For example, when pupils study a sensor, the Physics teacher teaches the mechanical aspect and the Natural Sciences teacher teaches the analysis of the measurements made by the instrument in question. Another innovation within our school is the use of an Internet platform to share the CarboSchools pupils and teachers' work in the different disciplines amongst themselves and with the rest of the school.

The CarboSchools project lasts a year, but each discipline works on it at a different time during the year when it is relevant to the curriculum, except for Natural Sciences and physics, in which it is possible to work on CarboSchools all year long if the teachers are willing to do so.

What activities does each do?

The project gives each pupil a chance to succeed by finding their place within one of the diverse activities carried out in the different subjects:

- ***Physical measurements and computer studies associated with natural sciences***

By collaborating with the INRA research unit, EPHYSE, pupils attend a scientist lecture on the greenhouse effect and the carbon cycle; they visit the Ephyse experimental site where research on the carbon cycle in the maritime pine forest is carried out; then they study some

of the sensors used on the site. The data from the site are exploited in the classroom and the mechanics of some of the sensors are studied. We have also installed a weather station and a CO_2 sensor within the school premises, thus allowing us to take and analyse our own measurements and to share them Europe-wide via the SchoolCO2web site.

- ***Natural Sciences***

The greenhouse effect, the carbon cycle, climate change, and the impact of human activities on the environment are included in the school curriculum for level „15-16 years old". Therefore, CarboSchools topics are easily integrated into the natural sciences curriculum.

We carry out experiments to simulate the greenhouse effect, biological processes like respiration and photosynthesis, and chemical processes like the dissolution and the precipitation of carbon in water. All these topics are explained during the scientist's lecture and then studied from an experimental aspect.

An annual awareness raising event

Each year, the CarboSchools pupils at the Max Linder School organise an annual awareness raising event within the school by presenting the year's work carried out in each discipline. The event includes activities such as an exhibition, a conference, workshops, demonstrations and games. It is open to other pupils at the school and from the neighbouring schools, parents, teachers and journalists; around 250 visitors in total during the day.

Activities carried out during the day:

- A poster exhibition of the different topics studied: climate, greenhouse effect, carbon cycle, sustainable development (in our city, in the region, etc), ecological footprint, the INRA laboratory our scientific partner
- Different experimental demonstrations which:
  - o simulate the greenhouse effect;
  - o show how we can measure the photosynthesis and respiration of different plants;
  - o simulate the diametric growth of trees in order to understand how trees absorb carbon;
  - o show how we can measure the acidification of CO_2 enriched water.
- Different stands where visitors can:
  - o calculate their ecological footprint
  - o watch slideshows on different topics
  - o taste organic food stand having participated in a game (see below)
  - o catch up on "carbonews" a newspaper written by the pupils
  - o leave a note on the "visitors' tree"
- A quiz game :
  Visitors are given questions which they need to answer correctly by reading posters or visiting stands, then for each correct answer, they can win a token, "carboron", they can exchange for a snack at the organic food stand (piece of cake or drink).
- „Jeu de l'oie" a French version of snakes and ladders which has been adapted by the pupils to include questions about the ecological footprint (transport, nutrition and household).

This event is the result of one year's work. In groups, the pupils prepare it using as a basis the topics they study in the different disciplines with their teachers. Each group has a task to do, but on the actual day everybody takes part in the entire exhibition. This aspect is particularly important because it means that all of the pupils must be connected and the success of such an event depends on this cohesion.

The pupils understand the important role that such collective activities play in increasing public awareness about climate change. In doing so, they themselves become aware that only group activities can change the process of global change.

- Civil Law and Social Education

The main aim of this subject is for pupils to work as independently as possible in order to analyse citizen rights and duties. As part of the CarboSchools project, topics are based on sustainable development. Pupils can study climate change in its different dimensions and the role of each citizen, like that of a consumer, a pupil, a businessman and a politician, etc. They calculate their own ecological footprint, as well as the school's, and they compare it to that of other countries.

- Economics

It is important for pupils to understand that climate change encompasses different dimensions like economics, society, politics and law, and that the three pillars of sustainable development are economics, environment and society. In order to archive this, they visit and study a local company which reflects this aspect in their company policies, for example, a waste management company.

In order to teach the business market, the teacher uses the example of carbon emissions trading.

- English and Spanish

Pupils practise and develop reading, writing, listening and speaking skills as well as grammatical and general language skills by studying a variety of climate change topics, such as ecological footprint, greenhouse gasses, food miles, waste management, etc. They carry out activities such as interactive games, debates, films, documentaries and experiments in association with Natural Sciences.

- Mathematics

To study statistics, graphs, variation rates and mathematical functions, the pupils exploit different meteorological and atmospheric data downloaded from websites and from our own sensors (weather station and CO2 sensor).

Case study 2:

The recipe for success when organising and working in class groups Lycée Max Linder, Libourne, France

by Stephanie Hayes and Mauricette Mesguich

Ingredients (no order of importance):

- *The people*

A team of voluntary teachers
A scientific partner (in our case INRA)

Motivated and interested pupils
Approachable and enthusiastic scientists
An efficient and available regional coordinator

- The means

Administrative support and acknowledgement for:
- Funds (transport, purchase of experimental equipment, production of posters, etc.)
- Time (preparatory meetings for the teachers, with the scientists and coordinator, etc.)

Technical and logistical help from involved laboratory technicians

- Motivation is the binding ingredient in this recipe.

Method

CarboSchools class structure

At the beginning of each year, a class of thirty-five 15 to16 year-old pupils is formed, two thirds of which is voluntary.

The whole class takes Maths, Biology and Geology, Civic Law and Social Education, English and Spanish. Approximately half the class takes the option Economical and Social Sciences.

The other half takes the option Physical Measurements and Computing.

The whole class therefore studies the scientific and citizenship aspect of climate change: one half studies the economical angle and the other half the physical science angle. This way, the three afore-mentioned aspects of climate change are covered within the project. The timetable is adjusted to make this kind of work easier: the two options are taught separately with different teachers, but at the same time, so that the two groups can be brought together when necessary.

The scientific partner

INRA (National Institute of Agronomic Research), research unit EPHYSE, Bordeaux

Activities which the scientists carry out include:

With the class:
- Giving interactive lectures
- Leading experimental site and laboratory visits
- providing support + guidance to pupils when designing + carrying out experiments

With the teachers:
- Providing and updating scientific knowledge
- Lending and installation of equipment
- Technical advice

Group work

At the beginning of the year, the pupils do not know each other. Therefore, interaction between students is encouraged via group work from the start of the project. It is also important to get pupils involved and motivated. We do this by posing some questions to the pupils in order to introduce the subject of climate change and the related issues of the 21st century. This stage of the process in the project is fundamental in order for the pupils to appropriate the CarboSchools project, and it is achieved through group work.

The pupils work in groups of three to answer one of the following questions.

- The mean global temperature is 15°C. Explain why. *This question should lead the group to describe the greenhouse effect.*
- What will our climate be like in the future?
- Why do we say that the global temperature will increase on average by 1 to 6 °C from now till the 2100? *These last two questions should lead the pupils to describe the impact of human activities on the carbon cycle and the greenhouse effect.*
- How do the terrestrial ecosystems react to the rise in temperatures: by absorbing or by emitting CO_2? *The pupils should think about the role of forests and continental waters in the carbon cycle.*

Visit to incineration plant

- Does my behaviour influence my local environment? What is my ecological footprint? *These questions should lead the pupils to define the concept of "ecological footprint" and to find an online calculator*.

- Do human beings absorb or release CO_2? Is it really reasonable to eat cherries at Christmas in our country? *These questions should lead the pupils to describe the impact of human activities on the carbon cycle and the greenhouse effect.*

At the beginning of the project, the pupils try to find immediate answers to these questions by carrying out literature research in groups (internet, reference books, etc.). However, during the course of the year, they explore the answers more deeply as a result of their participation in the project. They do this by:

- taking measurements by following scientific protocols and by using scientific instruments
- experimenting and modelling whereby a hypothesis is formulated and tested
- analysing data provided by the scientific team
- sharing results and data with the scientists and with other pupils via an internet platform

During the project, the pupils are allowed to change and reform their groups depending on the subject matter they want to explore, or with whom they prefer to work. However, they need to stay in the same group when producing the final output for a school exhibition. The preparation of this exhibition presents a challenge to the pupils, because, not only do they need to organise their work and share the different tasks within small teams, but all the teams need to interact in order to produce a coherent exhibition. The pupils work autonomously in their groups, being only guided by the teacher, and this way they learn to develop mutual respect when making decisions and suggesting ideas, etc.

Case Study 3:

Teaching climate change using a portfolio approach: linking scientific knowledge with technology and change in society

Isarnho-Schule Gymnasium, Kiel, Germany

by Bernd Blume

Global warming is a specific subject in the school curriculum. In this project, students work experimentally and responsibly, via scientific and technical investigation, to produce a portfolio of causes, effects and consequences of climate change. A portfolio approach is chosen as the method so that the students may have the opportunity to develop their special interests and responsibilities in this important topic. Moreover, the aspects of greenhouse gases are too varied to teach them all.

Aims of the project

For pupils to

- become acquainted with the relationship between science, technology and society by means of their own studies;
- Carry out individual experimental work to demonstrate the warming of the atmosphere as a result of the transformation, absorption and emission of greenhouse gas radiation; as well as to show the effects that warming can have on the worldwide ocean circulations system and biosphere, and that ocean acidification can have on

aquatic ecosystems.

- increase, via further investigations, their knowledge of technologies which could reduce the emission of greenhouse gases;
- become aware of their own responsibility for climate change from their individual work, including priorities for action.

Essentials

A complex subject such as climatology requires special basic knowledge in physics, chemistry and biology as well as in geography and history. The system of secondary education in Schleswig-Holstein (Germany) allows the combination of the above mentioned subjects and gives time for working together in projects.

Basic knowledge which should be taught before starting the project:

Biology	Chemistry	Physics	Geography
Cytology and physiology: cells – the basis of life.	Chemical equations; le Chatelier's principle; reactions of non- metal oxides with water; proteolytic reactions of inorganic acids and their salts; Brønsted's acid–base theory.	Solar radiation: Its absorption, reflection, emission and transformation.	Climate and global warming; climate zones and vegetation; the Gulf Stream and its effects on climate.
CO2-metabolism and energy exchange: photosynthesis and cell respiration	CO2: its solubility in water; influence of temperature on this.	Constitution and role of solar cells; energy transformation, e.g. wind energy into electrical energy.	

Activities and field trips

A complex subject such as climatology requires special technical knowledge of the relationship between science, technology and society, so visits to power stations and energy-saving-exhibitions are necessary. It is obvious that not all climate-relevant technologies can be taught, so looking at possibilities in the local area is recommended.

In the described project the following were visited:

1. Refuse incineration plant (Kiel)
2. Coal-fired power station (Kiel)
3. Energy-saving fair (organised by a parallel school class)
4. Scientific lecture on the SUGAR project: CO_2-sequestration from former methanhydrates, at IFM GEOMAR
   (NB- it is not necessary to do all activities on successive days)

Experimental work

During their experimental work, the students investigate aspects of the scientific background of climate and climate change by carrying out individual work.

They carry out at least ten of twelve experiments described in the CarboSchools on-line library:

- physics experiments on radiation and temperature
- biological experiments on metabolism (physiology)
- chemical experiments on the carbon cycle
- chemical-physiological experiment on combustion and metabolism

They should do at least three experiments with a physics emphasis, two with a chemical and two with a biological emphases. All experiments allow pupils to draw conclusions on aspects of climate issues.

Collecting waste gas

Measuring carbon dioxide in waste gas

The experiments, observations, results and error analysis are done in teams of two students for mutual help, but conclusions on climate questions and additional background research must be made individually to allow for individual reflection and assessment. Additional background research must be done on five selected experiments.

Note: even when quantitative measurements are included, only qualitative conclusions in a scientific context can be drawn. Application of acquired knowledge to aspects of climate must be done critically and carefully.

Putting the portfolio together

When preparing the portfolio, students are expected to comment on the following statements: *(Note: the climatic context of experiments is not given. It has to be deduced using one's knowledge and observations.)*

1. The greenhouse effect can be demonstrated.
2. Carbon dioxide is one of the greenhouse gases and so it is also responsible for the green-house effect.
3. Carbon dioxide in the atmosphere is part of the carbon cycle. Therefore, a natural green house effect exists.
4. Human activities are increasing the amount of greenhouse gases, especially of carbon dioxide, in the atmosphere, and are thus increasing the natural greenhouse effect.
5. The natural greenhouse effect has a role on global climate.
6. Additional amounts of greenhouse gases are causing global climate change.
7. Global warming may cause a change to the the worldwide ocean circulation system
8. Greenhouse gases and climate change can change the Biosphere.
9. Procedures to reduce the amount of additional carbon dioxide in the atmosphere exist.
10. Scientific exploration and implementation of methods to reduce greenhouse gases, and therefore intensified global warming, are necessary.

Instructions

1. Perform the prepared experiments (team of two students).
2. Describe observations and results. Present them graphically if possible (team of two students).
3. Analyse error (team of two students).
4. Explain the results of five chosen experiments by referring to the scientific background. Physical, chemical and biological aspects must be included in the final report (individual work).
5. Develop the climatic context of the chosen ten experiments referring to the statements above (individual work).
6. Choose one experiment, describe and explain one actual piece of scientific research on global warming/climate change (individual work).
7. Human use and development of climate technology: write a report including technical background, focusing on one subject (individual work).

Grading (Assessment)

Because of the differing school and grading systems in the different countries, it is up to the discretion of the teachers to determine to what extent the portfolios will make up the final grade.

Proposition: The final mark of the portfolio is 10% of the half year's mark in the subjects physics, chemistry, biology and geography.

Part-marks are given for the drafts on each experiment relating to instructions (10) and to the scientific background (5); two part-marks are given for the drafts on question 7 and three part-marks for the drafts on question 8. The final grade is calculated by division of the sum of the part marks by 20.

It is recommended that the teachers of the different subjects involved share the assessment by assessing the part of the portfolio relating to their own subject.

Note: the results of the investigations and research must be formulated individually; references must be included.

Organisation

Input

Day 1: Presentation of the project
Day 2. Visit to the coal fired power-station in Kiel and scientific lecture on CO_2-sequestration in methanhydrates at IfM-Geomar
Day 3. Visit to the refuse incineration plant. Afternoon: clarification of the chemical, physical and technical background to the processes in the two power plants
Day 4. Visit to an energy saving fair

Experimental work

Days 5 and 6: experimental work and interpretation (science room)

Portfolio work

Days 7 and 8; finish the portfolio. Documentation of science investigations and technical background (school library / information room)

Personal reflections

A visit to two plants perhaps provided too much input information for the students and they did not have enough time to clarify the chemical-physical and technical background of the processes. Therefore, a visit to only one plant is recommended. The quality of the results of the experimental work differed: not all students had clear results, because they worked too fast. However, their analysis of their own mistakes was acceptable and they developed a reasonable climate context to all experiments.

It is absolutely necessary that teachers of the different subjects plan, coordinate and work together and assess the portfolio in collaboration. Otherwise, it is too much work for the teacher.

Literature/websites

http://www.gkk-kiel.de/ (german only)
http://www.mvkiel.de/ (german only)
http://www.ifm-geomar.de/index.php?id=sugar#
ftp://ftp.ifm-geomar.de/downloads/NaT/Dokumente/VersuchsanleitungGolfstrom.pdf
methods to reduce the greenhouse gases, and therefore an intensified global warming, sequestration in methanhydrates at IfM-Geomar

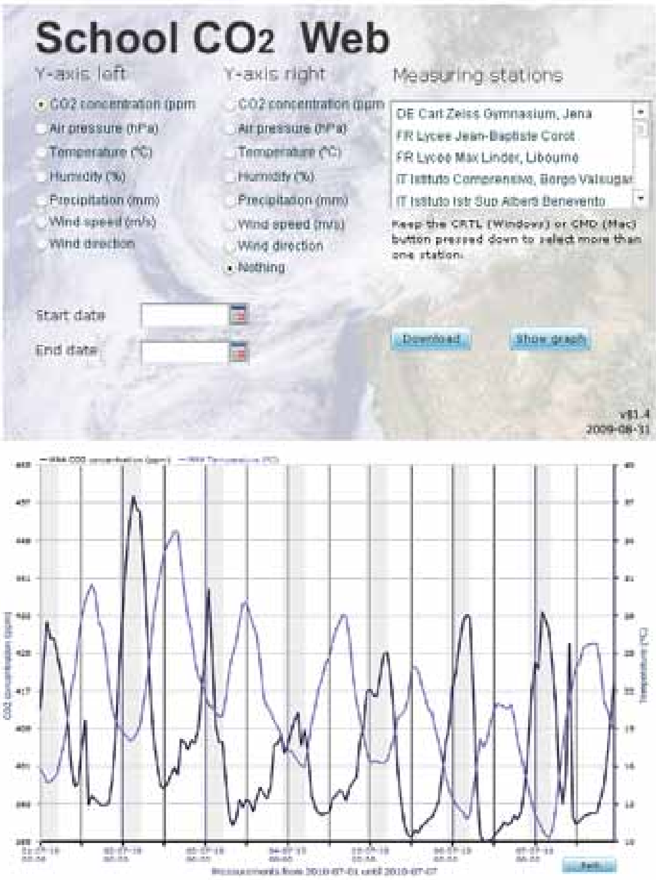
A prominent example of collaboration between schools and research institutes: the SchoolCO2web

Initiated in 2005 by the Centre for Isotopic Research (CIO) and the Department of Education (IDO) from the University of Groningen, The Netherlands, the SchoolCO2web starts with equiping schools with a CO_2 meter and a weather station on their roofs. Automatically, and at regular timepoints, these devices measure the CO_2 concentration and the atmospheric conditions and send the results to a central database. The collected data are accessible for both school pupils and researchers, and can thus be used for educational as well as scientific purposes.

A total of 14 measuring stations are currently active in 6 countries, providing pupils with an opportunity to really "see" the invisible CO_2 gas, to perform real measurements of their own, to compare data from different locations and to discuss their results and share their impressions with each other.

The SchoolCO2web database is accessible to anyone interested through a user-friendly interface at http://www.carboeurope.org/education/schoolsweb.php

Pupils learn how to interpret these data. They become familiar with the requirements for good measurements, learning that obtained data should be relevant, reproducible and trustworthy and learning how to achieve this. They also learn how to extract valuable information by means of spreadsheet programs and statistics. This provides a tool to ultimately involve them in data analysis, which is an important skill within scientific research. Using the SchoolCO2web brings about an excellent opportunity to acquaint pupils with good scientific practices in a multidisciplinary topic, including mathematics, physics, chemistry and biology.



This example of SchoolCO2web data (here one week in July 2010 in a Dutch school) shows a nice relation between temperature and CO_2-concentrations: during the day, the temperature increases, the air gets more mixed and the CO_2 gets more dispersed and thus lower; during the night, the temperature drops, the aire gets less mixed and the CO_2 more concentrated.

Chapter 3

Cooperation between Schools and Research

by Joachim Dengg,
IFM-GEOMAR, Leibniz Institute of Marine Sciences, Kiel, Germany

In spite of the massive impact of science on our everyday lives, the general willingness to learn about scientific concepts seems to be on the decline. Admittedly, cell phones, pharmaceuticals and microwave popcorn do not need to be seriously pondered as long as they do their job. And yet, to keep these things functioning and to improve on them, new scientists and engineers with a fundamental understanding of the underlying principles are permanently required. But even at the non-specialist level, at least a basic grasp of the scientific way of thinking is necessary in today's world to be able to follow the public discussion of topics like genetic engineering, global warming or – indeed – cell phone radiation.

However, fostering a greater degree of scientific literacy is an enormous challenge for schools. How to attract pupils to sciences with the means usually available: a small supply of possibly outdated materials, and yesterday's knowledge conserved in not-quite-up-to-date books? To match the present speed of developments in sciences, an investment in teaching materials and teacher training would be necessary that would quickly overcome any education budget.

Advantages of Cooperation

To alleviate this dilemma in science education, alliances between universities, or industry, and schools are being forged in an increasing number of places. By joining forces, schools can obtain access to additional resources and know-how, while companies and research institutions become more visible to young people.

The advantages of collaborations are fairly obvious in the case of schools: pupils can get a look at a research facility and learn first-hand about current topics in science. They meet actual scientists and they may even get a chance to participate in some aspects of research, using equipment not available at school. Pupils who are pondering the prospect of studying sciences themselves later-on are able to inquire about careers and find out through direct experience if doing science is "their kind of thing". Teachers, on the other hand, can obtain a practical context for some of the theoretical concepts studied in class, thus adding a new dimension to their teaching. Particularly for teachers who have been out of touch with new developments in science for some time, learning about new theories, methods or instruments can be invigorating. And after a visit to a research laboratory, teachers often leave with a good supply of illustrations or material they can subsequently apply in school. (Obviously, these are only some of the benefits for schools. Depending on the circumstances of a given cooperation and the partners involved, this list may turn out to be considerably longer.)

Graduate students demonstrating analysis of sediment cores to pupils in a research laboratory.

For industry and science, the main motivation for an engagement with schools is often a pressing lack of human resources (e.g. well-educated students) or a need for public visibility. In collaborations with schools, scientists gain opportunities to attract potential future university students to their field of expertise, to explain the benefits of their work to the public and to catch the attention of the media. Younger scientists in particular also appreciate the chance to learn how to communicate their science to non-specialists in simple terms.

Thus, quite obviously, close cooperation between science (or industry as it may be) and schools can be advantageous to both sides. Why, then, are practical examples of joint projects not all that common yet?

Obstacles to Cooperation

The most frequently quoted problem in starting school-research collaborations is “time”. Closely followed by “money”, of course. Oh..., and “lack of opportunity”! We are often led to believe that many schools and science institutions would be running fantastic joint projects, if only they had more time … money … opportunity ... you know ... Sorry.

Admittedly, time, money and opportunity are factors over which one usually does not have a lot of control. However, what if they were somewhat overrated? What if instead, individual properties like motivation, initiative and perseverance were to play a much more decisive role in the establishment and running of school-research collaborations?

This article is intended for readers who – in spite of external limitations - are interested in getting projects between school and science off the ground and who need a little motivation, a few suggestions for first initiatives and some encouragement for persevering with their projects. (Of course you may also continue reading if you have some time and money to spare, but for the moment it shall be assumed that these are very limited commodities.) We will try to give some advice on how the first steps can be taken to start initiatives, what common mistakes should be avoided, and what options there might be to finally address the issues of time and money once the first opportunities have been created.

Beyond the Day-Trip

To avoid confusion, by “school-research cooperation” we will be referring to longer-term partnerships between schools and science (or industry) that jointly arrange projects in which pupils are able to experience some aspects of science. Although a one hour lecture by a scientist in a school classroom may be a part of this, for the purpose of this article we are not talking about one-time events. Instead, we will focus on frameworks in which different types of activities are brought together to create a cooperation that will eventually be able to continue well beyond a school year. Furthermore, it will be assumed that real scientists are involved in the projects in some manner: while a spokesperson or public-relations person may well be able to give a good portrayal of science, they usually cannot teach the subject matter at the level desired here.

Our main reference point is the type of projects that CarboSchools has established in various countries. For pupils and teachers, these activities open up a new way of learning about the scientific background of global change topics by putting them into direct contact with researchers on a longer-term basis. Instead of just studying the theory of climate change in the confines of the classroom, the pupils get a chance to experience science first-hand in the field or at a research laboratory. In addition, scientists may also come to the school, report on their work and bring measured data from actual research campaigns for the pupils to analyse and discuss. (Some of these projects are briefly portrayed in this article.)

Scientist discussing hands-on experiments with pupils at CarboSchools spring school.

This is a phenomenal way of working (as the quotes from teachers and scientists in Chapter 5 demonstrate), but getting started often turns out to be a major obstacle. Unless you happen to be in a place where collaborations like this are already established as a funded project, kick-started by a generous sponsor or sparked off by some authority, the big question is usually how to proceed from the first tentative idea?

Box 1: Getting started

So, you have a plan for a nice project that could be done in collaboration between a scientist, a teacher and some pupils from a local school. But, although you have access to one of those, you have no idea of how to approach the others. And even if you had, how would you convince them to give it a try? Here are some suggestions:

Use "connections" to make contact: Frequently, people know other people who might be willing to make introductions. Teachers may have friends from university who went on to do science, or their pupils have parents who may know scientists. And on the other side of the fence, researchers may have children in school whose teacher might be interested in making use of a project opportunity, or scientific colleagues may know a teacher.

Do not rely on official channels: Sending a formal letter to a school or research institute may produce results, but very often it does not. Research institutions and schools are pestered with all sorts of requests and invitations, and often secretaries are charged with filtering out only the most urgent ones. Or, enquiries get handed on from one person to another, and nobody feels responsible for answering them. If possible at all, try to make personal contact with potential collaborators.

Look for people with track-records: Every now and again the media report about special projects by a school or about people who engage in scientific outreach. Approaching the individuals involved may not immediately result in a project, but even if they do not have time to commit themselves personally, they may know colleagues who would be interested in helping out. Particularly if school-science-cooperations are already in place (although maybe in a completely different field of research), the persons involved may be able to redirect enquiries to the right address.

Do background research: Websites reveal a lot about the interests of both schools and science institutions. If some school advertises the out-of-school projects it is undertaking, this might be a candidate interested in new opportunities. If a company or university has pages that display an interest in public outreach, chances are that they might pick up on an interesting proposal for a joint project.

Mind the age-gap: Not all scientists are able to work with pupils, and different age groups have different problems and advantages. Younger pupils tend to be more enthusiastic and ready to ask questions, but require more playful approaches and a greater degree of supervision. Older pupils work more independently and have greater background knowledge, but they may be more reserved and under more severe time-constraints. Particularly in a first project, scientists should feel comfortable with the age-range of the pupils they will be working with.

Start simple, start small: For "first-timers" there are many concerns that will prevent them from engaging in an activity that seems too large. By initially proposing small projects, the hurdle is not as high, and confidence and experience can grow later. Inviting a local researcher to give one presentation at a school, or inviting a small group of pupils for a visit to a research lab, can often be arranged with little effort, and it can be used to trigger subsequent activities.

Keep it short: Neither teachers nor scientists have unlimited amounts of time to spend on planning and carrying out projects. Thus, first projects should be short and concise, and they should be planned well in advance.

Explore expectations and try to fulfil them: Discuss what you have to "offer" as part of the collaboration. If visibility is what a researcher hopes to get from a visit to a school, try to turn the visit into a small event and to involve a local newspaper reporter. If teaching materials are what a teacher is looking for at a research institute, provide a small supply of brochures or a CD with the presentation you have prepared for the pupils.

Do not wait for funding: If funding is made a pre-requisite to getting started, a project may never get off the ground at all. However, small projects usually can achieve a great deal even without extensive funds. As a rule of thumb, one could say that if a researcher asks for payment for the materials he/she is using for practical work with the pupils, the project is already too ambiguous for a first step. Similarly, if a teacher needs special funds to pay for the class trip to the research laboratory, this cooperation will be problematic if it is to be continued on a longer-term basis. Reconsider, try to find simpler ways.

Taking the Initiative

A few suggestions that apply to the most common situations in initiating activities are given in **Box 1 "Getting Started"**. Essentially, the key is to take the initiative, make contact and – ideally as a common effort of scientist and teacher – develop a first and simple project that does not take up a lot of time or resources.

Pupils interviewing a scientist

In this first step, however, it is important to keep in mind that partner-to-be may not yet be aware of the advantages a common activity has to offer. In general, scientists do not get paid for helping out in schools, and teachers are not necessarily interested in teaching one researcher's particular type of science. To overcome initial reluctance, identifying the "added value" (as pointed out above) becomes vital. So, any contact should involve a perspective of what both partners may have to gain from such an enterprise.

Avoiding the Pitfalls

Once the decision has been taken to give a collaboration a try, the next challenge is to make the project an experience that all participants will gladly remember. For the sake of brevity, we will assume that any such activity will only be initiated if the teacher is certain that there is some appeal to the pupils, but this factor should never be taken for granted. Ideally, the science involved should hold its own fascination and it should be of direct relevance to the syllabus.

Box 2: Practical Considerations

Once a project has been arranged, there are various practical considerations that help to make it a success:

Appointments: Even if time itself may not be a restrictive factor in a project, timing is often crucial. Schools and sciences work on different time-tables, and these are often not easy to synchronise: scientists may not be aware of school vacations or examination schedules, and teachers certainly do not have the dates of major science symposia or excursions in mind. Planning ahead thus becomes vital to avoid unpleasant surprises.

Motivation: While teachers naturally have to care about all of their pupils, irrespective of their motivation and level of achievement, scientists cannot easily afford to spend time on students who are not interested or who lack the necessary background. Therefore, particularly if a scientist works with a school for the first time, it is better to select students who willingly join the project and feel suited for it (if this can be arranged). In cases where pre-selection is not possible, it is often a good idea to warn inexperienced scientists that not all of the students will show the same level of participation, and to provide alternative tasks for less-motivated students (e.g. by assigning a sub-group for photographic documentation).

Plan together: Planning a new project is best done in direct cooperation between scientist and teacher to guarantee that already at the design stage differing expectations and goals are avoided.

Take limitations into consideration: For both the school and the science lab there will be restrictions that need to be considered, such as size of individual laboratories, working hours of technicians, insurance issues or even trivial things like the number of seats available in a lecture room. Frequently, these are overlooked in the planning stage of a project and enter the scene at the most inconvenient time.

Variety: If pupils are forced to suffer through a succession of long presentations, their interest will invariably dwindle. Interspersing breaks is important, but having practical things to do is even better. Ideally, the pupils should be able to perform some measurements, do experiments or take samples on their own.

Use available expertise: Although this should go without saying: just as the scientists are the experts for the research part of the project, teachers are experts for education: they know best what length lectures should have for the age group of their pupils, how many breaks the children need to work off excess energy, etc. Plan accordingly. Also keep in mind that the factual knowledge of scientists is not their only area of expertise: for the pupils, they can be an invaluable example for the scientific way of thinking and consequent application of scientific methodology.

Clarity: Before the actual visit, the scientists should receive a clear idea of what level of detail is appropriate for the pupils they are going to face. Depending on age group, too simple a presentation may be just as detrimental as a too complicated approach.

Links to the syllabus: In general, if a scientific topic is interesting enough, a link to the curriculum is not strictly necessary. However, if an exciting activity can be hooked up to the syllabus, the pupils will probably not object to killing two birds with one stone by getting their coursework done as part of a new and interesting experience. For the teachers, a direct link to the syllabus greatly facilitates things because there is less extra-work and they can integrate the project into their teaching and grading.

Do not try to substitute school teaching: Although links to the syllabus are good, school-science collaborations should only accompany, and not substitute, the teaching of science at school. Researchers usually lack a didactical background and it is not their task to do a teacher's job. Besides, research should not relieve school authorities of their responsibility to guarantee a proper science education in school.

Interdisciplinarity: Working across disciplines is good, but not strictly a must. If it can be arranged, sharing a project between teachers of different subjects widens the scope, distributes the burden and provides greater flexibility in time. Note that most research is interdisciplinary by its very nature, because it requires mathematical and computational skills as well as foreign languages (mostly English).

Do not just entertain: It should be made clear to the students that a visit to a research facility or a project with a researcher is not like a trip to an amusement park. To emphasise this, it is useful to assign tasks to the students and to request reports. The pupils should be prepared for the visit by the teacher, and there should be a discussion and reflection after the event.

Venture onto new ground: Although this requires more work, when defining activities or tasks in projects such as these, one should not rely on standard text-book material that countless students have been working on before. If projects are based on aspects of a scientist's actual work, they are more genuine and exciting for everyone involved.

Avoid creating false impressions: Particularly if pupils are going to get involved in real science, they should be warned in advance that this will not be as exciting as they might expect: sometimes measurements have to be repeated over and over again, results may not become immediately apparent, because samples have to be analysed for weeks to come, or the signal to be measured may simply be absent because of bad luck or a false hypothesis. Yet, particularly with respect to decisions about future careers, this experience can be important for the pupils. Nevertheless, it is good to have a Plan B to fall back on if things do not work as hoped.

Recapitulation: If a project only focuses on imparting a first experience of science, this point may not apply, but if the transfer of actual knowledge or skills is important, then regular opportunities for recapitulation have to be planned for. Keep in mind that school children are not such independent workers as university students.

Grades: If project work is linked to the syllabus, grades may become an issue. Teachers may be faced with a situation where the reports become so specialised that it is hard to judge if it is the pupil's work or copied from some source only the scientist might be aware of. For pupils, it is important to know from the start if the supervising scientist will also be involved in the grading, because they will build a different relationship depending on the situation. It should also be made clear from the outset what will be graded and by what criteria. Experiments with negative results can still be good science if done and interpreted correctly, and this should be reflected in the grades.

Over-expectations: For scientists, it is difficult to judge what level of achievement they can expect from pupils at a given age. They may be in for a pleasant surprise, but they may also unconsciously apply the same standards as for a graduate student. Thus, at the beginning of the project the teacher should provide them with some reference material, e.g. a copy of a pupil's report from the year before.

Communication: Even if a project seems to be running well, keeping in touch will help to assure everyone involved that their work is appreciated and of interest to the other partners, thus boosting motivation. Should things go wrong, early warning signals can be registered and problems addressed.

The out-of-school-experience: Even if a scientist does not object at all to come to a local school and work with the students there, it should be kept in mind that being in different surroundings away from the classroom leaves a much more vivid impression with the pupils than any slide-show can hope to achieve. If possible at all, this is an element that should be included in any cooperation between science and schools.

Think of careers: Remember that scientists are not only researchers, they are also people and possibly role-models. Do not miss the chance to let the students find out how “their” scientists decided to enter this line of work and what stages they may have gone through to get to their present position. Pupils are often amazed to find out that this dedicated researcher originally wanted to become a football player or stewardess, that they may have had bad grades in maths, or that they spent some years in some foreign country.

Involving young scientists: While it is nice to have the director of a leading science institution talk to or even work with school kids, people in leading positions rarely have time for this sort of thing and will tend to delegate such jobs to younger staff such as post-docs or graduate students. This is okay, and in fact frequently better than the “original”: younger staff tend to have more time for projects, and the pupils can often relate to them much better than to a person who could be their grandparent.

Define products: Although “just a casual visit to a research laboratory” might be fine for everyone involved, it is often better to put some thought into what the desired tangible outcomes could be. If these can be defined in such a way that both the researcher and the school profit from them to some degree, the motivation to put some extra effort into the project is higher. So, instead of just asking the students for a written report, it might be better to have them design a poster which the researcher can also put up in his/her office. Or, a “reporting group” may be assigned the task of documenting the project on photographs or in a short movie. In some cases, with a little training, pupils may even be able to collect data that contribute to a scientific study. In these ways, all participants have something to show for their effort.

Acknowledge participation: For pupils and university students, participation in an activity like this can be important for their curriculum vitae. Providing certificates can be a good way to acknowledge their contributions. But even a simple thank-you note to everyone involved makes a difference.

Make student reports accessible to scientists: At the end of a longer project, pupils usually have to give a presentation or write reports. If it is made clear to them that the scientist will see these reports, this can be an added motivation to not gloss over some things in the hope that the teacher will not notice. On the other hand, this is also a good occasion for the scientists to see how much information has really caught on and how “their” pupils performed.

Commitment: One thing has to be stated very clearly: cooperation between science and school hardly ever works without some amount of special commitment. If scientists and teachers are only willing to do what they are actually paid for, they are best off just continuing their job as usual and not bothering about projects such as these. This of course has immediate repercussions on attitudes: if one side of the partnership invests extra work in the project, they are usually not happy about the other side sitting back and observing the process. So, in general, it is probably safe to state that the projects that work best in the long-term are those where all participants (scientists, teachers and students) are willing to spend that extra hour to make their project a success.

To build up and maintain the initial momentum, there are different elements that have proven their effectiveness with time. Again, these are explained in more detail separating in Box 2 “Practical Considerations”, and the readers can decide which of these suggestions might work best for their particular type of project. The most important aspect, however, is communication: expectations and goals should be clear to all sides, there should be continuous feedback between participants to avoid dead-ends or misunderstandings, and – particularly if further projects are envisaged - a common critical review at the end helps to determine what went well and what did not.

A central component of CarboSchools was the goal of putting science into a social context. Teenage pupils in particular are often not interested in studying science merely for the sake of science alone. They are aware of the problems that affect the world around them, and they feel that they want to have an impact on how their future develops. Consequently, they want to know how science is relevant in affecting this future.

One implication of this is that socially relevant science is more attractive to pupils than abstract knowledge. “Why are we changing the climate and how can science help to counteract this?” is clearly a much more exciting question than “How does photosynthesis work?”, although both are closely related. Another “side-effect”, however, is that researchers and teachers will be asked about the social implications of their science, and they may be confronted with discussions on these topics. (In fact, this citizenship-aspect of education was very much a desired by-product of many of CarboSchools‘ activities.) Many researchers welcome this approach, but sometimes codes of conduct in public or institutional policies may inhibit open exchange. Thus, when planning a project based on social relevance, this issue should be addressed early in the planning stage.

Furthermore, while pupils are usually quite willing to accept that the experiments they are performing have been done before and may lead to a well-known result, they may react much less benignly when they get the feeling that they are being goaded toward a foregone conclusion. Thus, mixing science teaching with an “agenda” (no matter how well-meant) can backfire.

If successful, these projects have a tendency to quickly become more ambitious than originally planned. By itself, this is not a bad thing because it may provide a nice challenge for everyone involved. However, care has to be taken to retain a sense of realism in terms of available background knowledge, goals and time investments.

Going Steady

After the first successful activities, there may come a point where the initiative has increased in size: school projects have become more elaborate, additional teachers have caught on and want to join in or start a project on their own.

This is where the factors of time and money finally do enter the scene, if they have not done so before. As initiatives make the transition from “project” to “established cooperation”, they leave the realm where one or two people can run them in their spare time or squeeze them into their regular work schedule. In the CarboSchools experience, the role of a coordinator becomes essential to match-make between teachers and scientists, to find funding and to arrange schedules. Box 3 “Project Sustainability” tries to address some of the key issues in this context.

This is also the phase where institutional back-up becomes a concern, both at school (does the headmaster / school authority support this work?) and in research (is an institution willing to engage in these projects on a more permanent basis?). In most places, there is no real institutionalised framework for school-research collaborations, so special constructions have to be arranged. Frequently, these take the form of a “continuous sequence of intermittent solutions” (e.g. proposals for third-party funding), a modus operandi not unfamiliar to

French pupils making a movie at the CarboSchools Spring School

researchers, because a large part of research is carried out in exactly this way.

At the End of a Day...

Hopefully, this article was able to convince you that it is not only time and money that determine the success of school-research collaborations. However, after all these caveats and recommendations, one should not finish without saying: projects between school and research can be great fun and extremely rewarding! After a project done right, everyone involved should be feeling duly exhausted, very happy and genuinely proud of themselves. This is what you should aim for!

Box 3: Project Sustainability

If all parties involved decide that their common work is worth pursuing in the future, new issues eventually arise:

Time Management: Although schools cannot assign the time of pupils and teachers at will, schedules can be arranged to accommodate project work more easily. Thus, placing a double science lesson at the end of a school day may allow the pupils to go to a research laboratory and continue their work into the late afternoon. Besides, double lessons also allow more time for experiments in the classroom or school lab.

Funding: At some point, these partnerships do require money that cannot be "nicked" off some other activity on a longer-term basis. Usually, secure funds are not readily available, so the search for sponsors, grants or other third-party funding is on. In many cases, getting money for equipment, travel or consumables is not too hard, but money for staff is an entirely different issue. Unfortunately, general recommendations cannot be given with respect to sources of funding, because circumstances are very different from country to country. However, in most cases it would be wise to explore different avenues and not concentrate on only one "traditional" option.

Visibility: No matter who pays, visibility is a key factor for funding: sponsors want to be acknowledged, and foundations want to be able to show results. Thus, establishing a track-record of public outreach in the context of school projects is important. Participation in competitions (both at the level of individual pupils or between projects or schools) may help to raise awareness that the initiative is able to show achievements.

Events: While participating in activities may be sufficiently rewarding for everyone, occasional highlights are always welcome. Particularly in sciences, there is not much opportunity to "shine" with a special achievement, so creating events where outstanding results can be shown or publicly acknowledged helps to keep attraction high. At the same time, special events can increase the public visibility of the research institution or the status of the school.

Coordination: When several projects are running at the same time, coordination becomes an issue. If a dozen teachers all ask the same scientist for project cooperation, that person's enthusiasm will rapidly decline. Similarly, if a common exhibition is to be organised or a common proposal to be written, someone has to take the lead. Sooner or later, a project coordinator becomes vital.

Establish a framework: A loose assembly of activities without clear goals and a name does not look attractive to potential sponsors. A collaboration should build up an identity and stay within a well-defined context. However, a sense of proportion is important: too narrow a frame restricts activities too much, while too diverse a setup is confusing to clients and supporters.

Science educators: At some point it may become beneficial to involve science educators in a project. They can offer advice on linking projects to curricula, help in evaluating the effectiveness or suggest useful methods. Keep in mind, however, that you are first and foremost running the project for the pupils and teachers and not for the science of education.

Discourage passive "consumption": being able to provide completely worked-out, pre-packaged projects to schools or researchers may look tempting, but in the long run it reduces their motivation to make original contributions. Eventually, collaborations become lopsided and even strained. Retaining a sense of responsibility for all participants produces healthier relationships.

Avoid being repetitive: In partnerships like these, "routine" is good, but "continuous repetition" kills the enthusiasm of everyone involved. Do not run the same project over and over again with the same instructors. Pupils need to feel that they are doing something new, and scientists in particular love to try out new things. Re-invent your projects afresh from time to time.

Set limits: As large as the temptation may be to welcome anyone interested, there will always be limits to what a school or a research institution can support. A policy to acknowledge those limits and to consciously stay within them prevents a sentiment among the participants of feeling exploited. In addition, it reduces the risk of spreading resources too thin and loosing the quality of the approach. Learn to say "no" to enquiries and to give breaks to your co-workers.

Do not expect miracles: Even with the best of tutorship and encouragement, not all of the pupils will turn into unequivocal science-enthusiasts or future graduate students. And even if some do, it may not become visible for some years. The best to hope for on short to intermediate time-scales is that pupils liked their activities, that teachers felt it enriched their teaching and that scientists enjoyed it enough to do it again.

Aim for results: Running attractive projects is great, but if there is no visible output, there is nothing to show when the need arises. Participation statistics, press clippings, web pages, photo documentation, student reports or evaluation results can all help to document that a project is doing a good job.

Appendix: Case Studies

Kiel, Germany

In Kiel, the Leibniz-Institute of Marine Sciences (IFM-GEOMAR) has been hosting single pupils for "job internships" since the early 1990s. Although formally no cooperation existed with any single school or teacher, these practicals were offered as a result of continuous enquiries by pupils who needed to do this kind of job training as part of the curricular requirement. Practicals encompass a one or two week period in which the pupils are involved in practical work in different departments of the institution, with the goal to get initial job experience and to get to know different aspects of marine sciences. In 1998, the institute explored a new venue by expanding these internships via an option for the pupils to write web pages for the general public (and pupils in particular) on specific topics in marine science. The results quickly convinced the supervising scientists of the merits of this approach, and when in 2003 the institution was approached by the Robert-Bosch Foundation with the idea of establishing a joint "NaT-Working" project (based on the name of the funding scheme) between schools and marine research, the ground was well prepared for this formal collaboration.

The resulting initiative received start-up funding by the Bosch Foundation for a period of first 3 and then another 2 years, and it is still running today. Its premises are: to foster the fascination for sciences in pupils, to involve marine scientists at the core of this work, to engage the teachers in the projects, to tailor each project to the scientists and the research topics available, as well as to the time-frame and age of the pupils, and to firmly tie this work into the context of public outreach of the science projects. With time, a partnership between several schools and the research institution developed, laying the foundations for additional funding proposals in the context of EU's 7th Framework Program (CarboSchools), or national research initiatives (German Excellence Initiative and Collaborative Research Centres).

By now, "NaT-Working Marine Research" has expanded well beyond a local initiative and is running school projects that are crossing borders and even continents. The spectrum of projects ranges from course work at grade 5 (e.g. after-school experiments on selected aspects of the marine environment) to student theses in grade 12 that run for one year or more and which may involve participation in international research expeditions to the equatorial Atlantic Ocean or to South America.

The core-staff presently consists of 4 people (most employed for the project on a part-time basis), with contributions by teachers at 10 partner schools and by scientists at IFM-GEOMAR. As the projects concentrate on experimental work on selected topics, the number of pupils directly involved is fairly small (in the order of around a hundred per year), but special events in which these pupils display their work to the general public multiply the audience considerably.

Paris, France

Near Paris, scientists from the LSCE (Laboratoire des Sciences du Climat et de l'Environnement) have participated in school activities for a long time. They are often parents of pupils and they began by visiting their children's classroom to talk about their work or to show experiments. Until 2006, these activities were fairly spontaneous, occasional and not linked to each other. During the scholar year 2006-2007, with the help of funds from Île-de-France (administrative area around Paris) to support the European projects CarboEurope and CARBOOCEAN, more continuous actions took place. A coordinator was recruited, to establish cooperation between secondary school teachers and scientists on the topic of the carbon cycle. These actions were extended for three years by the EU funding for Scientists from other laboratories of IPSL (Institut Pierre Simon Laplace, a research institute about climate science including six laboratories) were also involved.

First contacts were established with the help of educational inspectors who allowed the coordinator to present a proposition of coordination in front of secondary school science teachers. Word of mouth then carried this on. School activities could last from three weeks (three weekly sequences of three hours) to all school year long, with pupils from 11 to 18 years old. They included experimentation in the classroom, visits to the laboratories, work on data and presentation of results during public meetings. The best sequence turned out to be: - a visit to the classroom by the coordinator or a scientist to stimulate pupils – experimentation in the classroom, including work on scientific literature or data, protocol writing, protocol criticism, experimentation itself – laboratory visits –presentation of results.

During three school years, more than 800 pupils, 50 teachers and 10 scientists participated in educational projects. From these activities, we learned that exchanges between teachers and scientists, without pupils, are absolutely necessary, as is the existence of a coordinator, recruited by the laboratory to establish relationships between scientists and teachers and to coordinate all the projects.

Firenze, Italy

In the 1990s, the Institute of Biometeorology of the National Research Council responded to the need for teachers to integrate scientific methodology and tools in their lessons, and started experimental projects on meteorology for primary and secondary schools. These collaborations started as a result of friendships among scientists and teachers or parents of pupils. At the beginning, most of the activities were organised in the form of seminars and frontal lessons, because the educational system was strongly rooted in the use of frontal lessons and text books. In addition, regional and local education projects funded by public institutions (Regione Toscana, Provincia Autonoma di Trento) led to the publication of outcomes like booklets and videos for pupils and teachers.

The scientists' and teachers' motivation, and the production of results with positive feedback, sustained the partnership through time, and the rising interest in climate change led to a wide range of activities and projects that have been carried out even by research teams not belonging to the CarboSchools partnership.

In 2006 the international project 'Teacher-Scientist Partnership' started, by which stronger partnerships between scientists, teachers and pupils developed on the basis of training courses for teachers and hands-on activities for pupils.

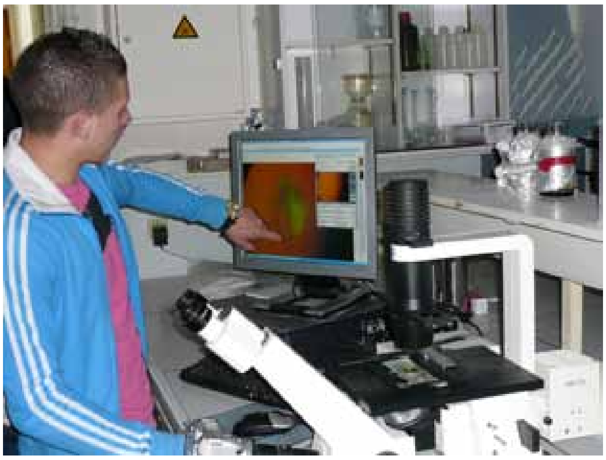
CarboSchools projects are characterised by an innovative educational approach based on the use of advanced technical equipment provided by the researchers, aiming at obtaining knowledge and focusing on certain aspects of climate change and the carbon cycle through field experimentation performed by the pupils. The learning process through long term field projects brings the pupils closer to real research activities. In addition, since field work generally needs patience and proper skill, this experience can also be useful to identify personal skills, interest and attitudes of each student.

The core staff working in CarboSchools is composed of one senior researcher and two young researchers who sustain the partnership (on a part-time basis) and collaborate with other scientists and with 7 schools and 10 teachers.

Bergen, Norway

In Bergen, cooperation between scientists from the Bjerknes Centre for Climate Research and secondary school teachers/students started in 2005. The initiative came from two FP6 integrated research projects, CARBOOCEAN and CarboEurope, which both had contractual obligations to convey their research results to the public, and in particular to the young people who are the decision-makers of tomorrow. The scientists from the Bjerknes Centre for Climate Research who were to be involved in school projects worked primarily with the marine carbon cycle, e.g. measuring CO_2 in seawater.

The contact between scientists and teachers was established by sending a general e-mail request to a small number of teachers and schools in Bergen. The cooperation started with one teacher from the upper secondary school Bergen Katedralskole and one scientist and one engineer from the Bjerknes Centre, and during the project the pupils performed experiments in the field (at sea) and participated in post-cruise analyses at the research institute's laboratory. Prior to this, teachers visited the research centre and scientists visited the school, and these initial meetings and discussions were vital for the implementation of the project, e.g. how to make the research project fit with the curriculum, and how to prepare and motivate the pupils for such projects. Unfortunately, no grading was given in the first year of projects which made it difficult to ensure that all pupils complete dtheir final reports. The project had practically no funding during the first years, but from 2008, the project became a part of CarboSchools, with funding from EU's FP7. In the first years the collaboration got some attention in the local newspaper, and a movie and posters were produced which have been shown at several international research meetings.



One pupil explains an experimentation to determine effect of acidification on organism's calcification.

Since 2008, the cooperation has been extended, and we got help from the Science Education Centre at the University of Bergen to get in contact with more teachers/schools. At present there is cooperation with teachers and pupils from three upper secondary schools in Bergen. The focus of the projects varies depending on the subject of the teachers; biology, technology and science, geosciences, etc., and the projects last from three weeks up to a whole school year. The projects are primarily based on experimental work outdoors, at the school, and at the research institute laboratories, but introductory lectures and classroom presentations and calculations are also performed. The work is graded, which is certainly an advantage compared to previously.

During the last three years, CarboSchools in Bergen has been run (part-time) by two scientists, and there is in general a large willingness amongst research colleagues to participate in time limited activities, like giving talks, participating in debates, being interviewed by pupils, etc.

CarboSchools library's main page

Chapter 4

Experiments – A Sneak Preview of the CarboSchools Library

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LSCE-IPSL, Paris, France

Experimenting is a stimulating and motivating way of introducing and teaching science to pupils. The main reason pupils love doing experiments is because it is "fun". Learning and having fun at the same time is mostly a rare opportunity, which should be taken advantage of whenever the chance presents itself. Through experimentation pupils can visualise abstract ideas which they may have read in books or heard in frontal lectures from their teachers in the classroom.

However, in the different European countries, the feasibility of experimenting in class is varied, being mostly limited by curriculum constraints and, unfortunately in many cases, a lack of resources. Even within a country, for example Germany, where the educational system lies within the jurisdiction of the different state governments, any curriculum differences will also mean different approaches to a subject matter.

Pupils often wrongly consider an "experiment" to be a hands-on activity involving the performance of a pre-defined method ending in an expected result. However, one of the "beauties" of an experiment actually lies in the fact that something can go wrong and pupils are allowed to make mistakes. Through these "accidents" experiments will have a bigger educational value allowing pupils to learn from their mistakes.

Ideally, pupils should be given the chance to formulate their own questions, and, with the guidance of the teacher, to think up their own experiments and test their hypotheses. In the real school setting, this idealised picture takes a lot of time and effort which are usually not available. One of the purposes of the experiments developed in CarboSchools is to provide the teacher with a broad range of activities to introduce the concept of the Carbon Cycle in the classroom; these can be used directly, or they can be modified and adapted to specific needs. These experiments can act as a basis for pupils, inspiring them to reflect more on the carbon cycle and subsequently think up their own experiments.

The majority of the experiments developed for CarboSchools can be done with minimum costs and do not need special equipment. Care was taken to ensure that the experiments developed can be duplicated in the classroom with minimal preparation time for the teacher. However, some activities do require expensive instruments and in these cases the assistance of a research institute should be sought. This will bring the welcome advantage of bringing the pupils in contact with "real" research and "real" scientists in a "real" science laboratory, as discussed in Chapter 3. The diversity of the approaches in the different CarboSchools projects is reflected in the variety of activities and experiments developed for this project. Detailed descriptions and all experiments are available on-line in the Carboschools library (www.carboschools.org).

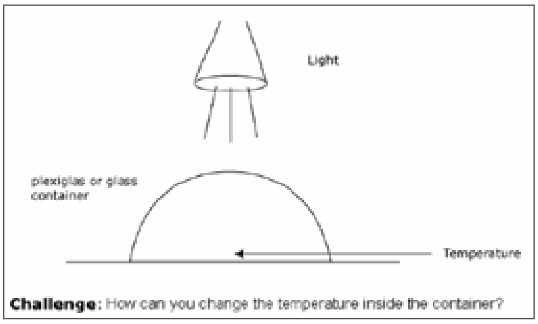
Three representative experiments were chosen for this chapter, each representing a compartment of the earth's environment which plays major roles in the Carbon Cycle: the atmosphere, the hydrosphere and the lithosphere. These examples were chosen to reflect the structure and the build up of the experiments in the library, as well as to show the diversity of available materials.

Atmosphere

How is global temperature regulated? An experimental representation

Introduction

This is a simple first experiment to introduce pupils to climate change. The following experimental set-up summarises temperature regulation at the Earth's surface.



The soil or sand in the container represents the Earth's surface and the lamp represents the sun. The container represents the greenhouse gases (but NOT the atmosphere), because the glass or plexiglass have the same transparency and absorption properties in relation to the light, which is transparent to visible light, but opaque to infrared radiation. This experimental set-up also illustrates the origin of the name "greenhouse gas/effect" as we are in effect creating a greenhouse.

Aim

To help students understand the phenomena involved in temperature regulation at the Earth's surface.

Preparation time:	10-15 minutes
Activity time:	2 hours
Type of activity:	Hands-on experiment
This activity has been tested on students aged:	14-17
Application:	Physics, light absorption and reflection
Time for data analysis and discussion:	1-2 hours
Prior knowledge required:	Background information about greenhouse gases and atmosphere
Cost:	Low, materials usually already available in schools
Degree of difficulty:	Easy

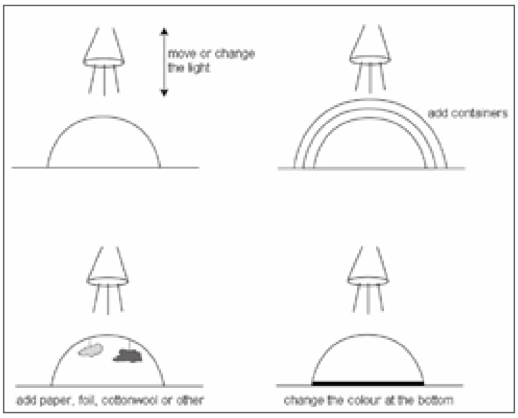
Materials

- Transparent containers such as salad bowls (glass or plexiglass), which can fit into each other
- Thermometers
- Different coloured sand and soils, white and black paper
- Desk lamps

Procedure

1. Set up the experiment with just the up-turned container, lamp and thermometer as shown above.
2. Set the following challenge to the pupils: to change the temperature inside the container. They should not forget that the set-up represents the Earth and sun etc, thus they must find realistic solutions (for example, switching the lamp off to reduce the temperature would be the same as extinguishing the sun, which is not possible).
3. If you wish, set a more precise challenge to the pupils: to increase the temperature by 1 degree by suggesting different solutions. This is interesting as it shows the pupils that different phenomena can have the same results; the temperature at the Earth's surface can vary as a result of different processes.

Possible solutions (but let the pupils find them on their own first)



- Placing the lamp further away or nearer to the container corresponds to when the Earth is further away from or nearer to the sun depending on its trajectory, or to when the sun is stronger or weaker. Changing the power of the lamp can also be accepted as it represents the same phenomenon.
- Increasing the number of containers corresponds to an increase in greenhouse gases. In order to observe a temperature gradient similar to that which is in the atmosphere (the troposphere to be precise), place a thermometer between each container.
- Changing the background colour corresponds to the changes in general atmospheric colour (presence of clouds, for example), or in Earth surface colour (the average colour of the Earth's surface is darkened as a result of melting ice, or is lightened due to the spreading of deserts).
- Adding pieces of paper or aluminium foil, etc. correspond to clouds and aerosols. This is interesting because the results are unpredictable. Clouds and aerosols are big unknowns in climate change prediction models.

How are the measurements carried out?

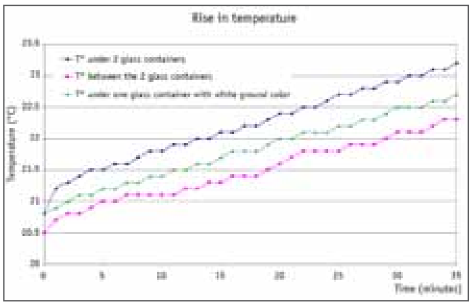
The problem with this experiment is that the temperature under the container(s) takes time to stabilise (more than 50 minutes). This means that it is either necessary to wait for stabilisation in order to obtain comparable temperatures, or to start the experiments with the same initial temperature conditions and to take good notes of the temperature changes. The second solution is easier to carry out in class, allowing the pupils to quickly see the differences in temperature (between 2 and 5 minutes).

Some examples of experimental set-ups

These examples are taken from the work carried out by a secondary school class (Lycée de Vilgenis, Massy, France) in their Natural Sciences class. The activity was carried out in two one and a half hour sessions, including the time needed to take photos and to make the posters. They opted for the second measurement solution (noting the temperature changes), as they did not have time to wait for the temperature to stabilise.

1) Increase in greenhouse gas concentration

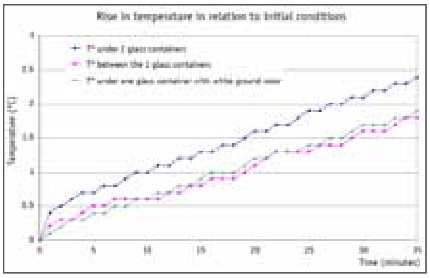
Experimental model: the pupils chose to put two glass containers inside each other. The temperature was measured under both containers (blue curve in the graphs below), and also between the two (pink curve)



Results

- *Green curve : temperature under one glass container, control experiment*
- *Blue curve : temperature under two glass containers (corresponding to a a situation where greenhouse gas concentration is higher)*
- *Pink curve: temperature between the two glass containers (corresponding to the temperature taken in the middle of the troposphere)*

We can see in the graph that the temperature varies at the beginning of the experiment. In order to obtain more comparable results, the pupils produced a graph showing the rise in temperature in relation to the start of the experiment (see graph below).



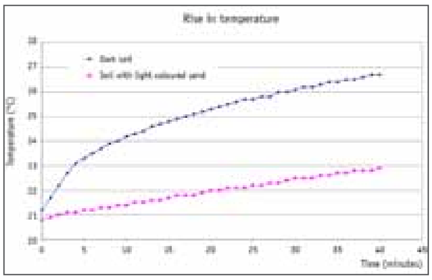
Rise in temperature, in relation to initial conditions over time

- *Green curve : temperature under one glass container, control experiment*
- *Blue curve : temperature under two glass containers (corresponding to a situation where greenhouse gas concentration is higher)*
- *Pink curve: temperature between the two glass containers (corresponding to the temperature taken in the middle of the troposphere)*

These experiments show that as the number of glass containers between the source of light and the ground is increased, the ground temperature increases. Furthermore, a temperature gradient is created by increasing the layers of glass. Thus, this experimental model is a good analogy for greenhouse gases.

2) Changing the colour of the Earth's surface

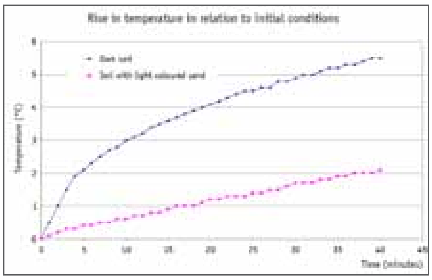
Experimental model : (i) under a container with dark soil, (ii) under a container with light coloured sand.



Results

- *Pink curve : temperature measured with light-coloured sand*
- *Blue curve : temperature measured with dark soil*

Once again, as the initial temperature conditions differed a little, the pupils produced a second graph to show the rise in temperature in relation to that measured at the beginning of the experiment.



Rise in temperature in relation to initial conditions over time

- *Pink curve : temperature measured with light-coloured sand*
- *Blue curve: temperature measured with dark soil.*

These experiments show that the colour of the ground has an influence on its temperature: the darker the ground, the higher the temperature. This phenomenon can be explained by the fact that dark soils/surfaces have higher visible light energy absorption.

During a discussion with the pupils, it was highlighted that the melting of ice has a serious effect on the increase of temperatures: a rise in temperatures leads to the melting of polar ice caps, the Earth's average colour darkens (white is replaced by the dark blue of the oceans or by the brown of the continents), and consequently the energy absorbed by the Earth increases, thus leading to an increase in surface temperature and the subsequent melting of ice, etc. A vicious circle known as "positive feedback" has been started.

Summary of experiments carried out at lycée de Vilgenis

Hydrosphere

Interaction at the Air-Water Interface

Introduction

What happens at the surface of a body of water (e.g. a lake or the sea) when carbon dioxide is dissolved in it? There is a constant exchange of gases between the air and water surfaces. One of the factors which may affect this exchange is temperature. In a large body of water, what happens to the gas that is dissolved at the surface and not transported to deeper layers? It will stay in the surface and equilibrate with the concentration of the gas in the atmosphere.

Aims

To demonstrate gas exchange at the boundary layer between water and air and to relate this to what happens at the ocean-air interface. To show how temperature affects this process.

Preparation time:	15 minutes
Activity time:	15 - 45 minutes
Type of activity:	Hands-on experiment
This activity has been tested on students aged:	10-12 yrs., grades 5-7
Application:	Physics, Chemistry,
After-school activity	
Time for data analysis and discussion:	20 minutes
Prior knowledge required:	Acid-base interaction,
concept of “indicators”	
Cost:	Indicator (12€/250 ml),
Floating candles (3€)	
Degree of difficulty:	Easy

Materials needed for the experiment: salad bowls, floating candles, indicator solution and white background.

Materials*

- 6 salad bowls with the same diameter (2 salad bowls are for the control)
- Distilled water at room temperature
- fFrozen distilled water (ice cubes)
- Matches
- 12 white floating candles
- White paper background
- Universal indicator (McCrumb)

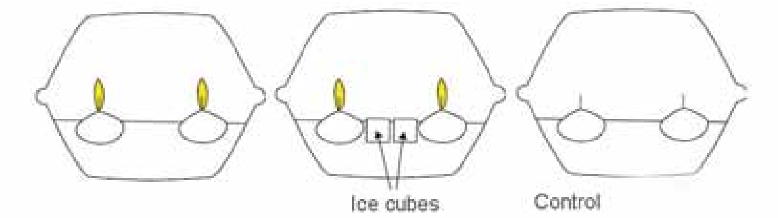
**To save on materials, you can do the experiments one at a time. In this case, you will just need two salad bowls and 4 candles.*

Four lighted floating candles are placed in the bowl with water. Note the colour of the water at the air-water interface.

Procedure

1. Place three bowls on top of a white background. Fill these with the same volume of distilled water about ¾ full. Cool one bowl with the frozen distilled water (ice cubes). Add several drops of the McCrumb universal indicator to the bowls. Make sure that they have the same intensity of green colour.
2. Light 8 floating candles and place four each in two bowls. Put the four unlighted candles in the third bowl. This will serve as your control. Cover the bowls with the remaining 3 bowls. Take note of the colour of the water at the start of the experiment.
3. Observe the change in the colour of the water in the bowls. To see any changes, look at the air/water interface (boundary between air and water).

The bowl is covered with the other bowl. After some minutes, the candles are extinguished after they have used up all the oxygen inside. The control is the same set-up with candles unlighted.



Results and Points for Discussion

- What colour change did you observe? What does this indicate?
- Where does the colour change take place? Did all the water in the bowl change colour? What does this imply in relation to the oceans?
- In which bowl was the colour change more visible? Why do you think this is the case?

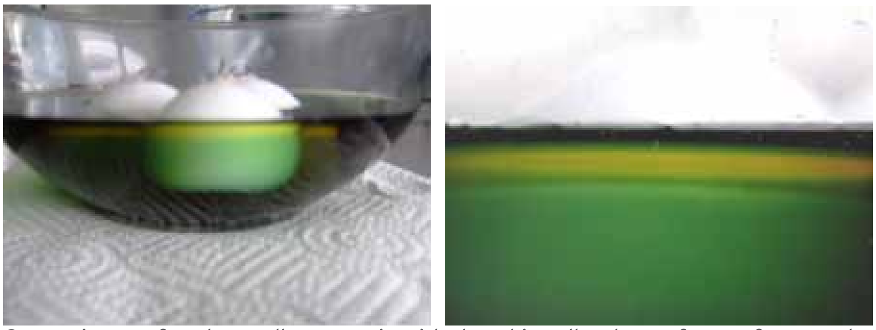
Notes

I. The colour change from green to yellow (basic to acidic) occurs only at the surface of the water, which has direct contact with the air above it. The carbon dioxide produced by the burning candles dissolves at the water surface making it acidic. Consequently, since there was no excess CO_2 (no lighted candles) introduced into the control bowl, there should be no change in colour of the water here.

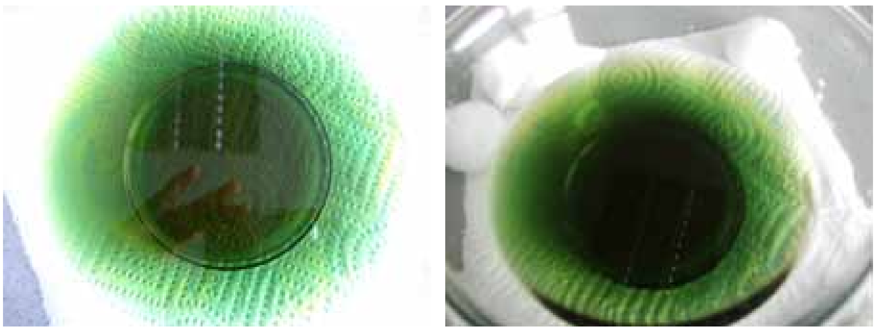
II. Without agitation, the colour remains at the surface of the water and does not readily diffuse to the deeper part of the bowl. In the ocean, CO_2 dissolved at the surface is only effectively removed from the atmosphere if this CO_2 is physically transported to the deeper layers by convection.

III. The cooled water in one bowl should be more yellow because of a higher solubility of gases in cold water. However, since the water in the bowl has a uniform temperature, there is no transport of the acidic water to the bottom of the bowl.

IV. In this experiment distilled water was deliberately used to show the pH change at the surface of the water using the McCrumb universal indicator. Seawater can not be used for this experiment because the indicator is not sensitive enough to a small pH drop. The buffering capacity of seawater will lead to a smaller change in pH compared to distilled water.



Some minutes after the candles are extinguished, a thin yellow layer of water forms at the surface. This indicates acidification of the surface layer because of dissolved carbon dioxide.



Colour of the water before and after the experiment with the lighted candles.

Additional Experiments

Remove the covering bowl and let the set-up stand for a while. Observe the colour change on the surface of the water. After several minutes, the yellow colour will disappear because equilibration with the surrounding air, which has a lower concentration of carbon dioxide, has occurred. This occurs faster if you stir the contents of the bowl. To demonstrate convection remove the covering bowl from the set-up without ice cubes. Add ice cubes and then replace the cover. This will cool down a part of the surface water and this will start to sink to the bottom of the bowl.

The preceding experiments make use of simple materials usually available in the school or at the local grocery store and can be performed inside the classroom. However, several of the CarboSchools projects and experiments were designed for students in the upper secondary level, that is, for pupils who have enough background knowledge of the carbon cycle and hence are equipped to understand and perform more complicated experiments. Therefore, some experiments in the CarboSchools library require some special equipment, which can be provided by a partner institute.

The following outdoor experiment on soil respiration is an example of an activity requiring specialised equipment: it requires a gas analyser, which is usually too expensive for a school to afford. However, the experiment also gives an alternative method using a cheaper instrument. The methodology described below is used in actual research, thus making it even more fascinating and interesting for the pupils.

Only the soil respiration part is described in this chapter. The determination of other parameters like soil moisture, bulk density, soil pH, etc. can be downloaded from the library.

Lithosphere

The soil breathes

Soils represent huge carbon storage and play an important role within the carbon cycle. Carbon dioxide is assimilated by vegetation and is soluble in water, resulting in a change to a solid form such as carbonates and organic matter in marine and terrestrial ecosystems.

Figure 1 The carbon cycle (http://web.ticino.com/gfwp/scuola/oss_2_co2.pdf)

Carbon dioxide also returns to the atmosphere from soils. Soils, in fact, are the substrate where living organisms interact with non-living materials, where the decomposition and mineralization processes by microorganisms and bacteria take place, and where other exchanges develop between the soil and atmosphere. The carbon dioxide produced and its diffusion to the atmosphere is called “soil respiration”.

The soil respiration process is strictly dependent on the characteristics of the organic matter in a given soil, the pedoclimatic conditions and the presence of organisms. The transformation of the organic material ranges from 1 to 10 years, depending on the vegetal ecosystem (W. Larcher, 1993). Soil moisture and temperature control the mineralization processes by living organisms, thus also the CO_2 release to the atmosphere. Furthermore, CO_2 efflux is facilitated by high soil porosity.

This activity not only shows the carbon dioxide exchange between the atmosphere and soil, but also how vegetation influences this exchange.

Pupils can compare different soil use or cover. For instance, pupils can run their measurements in a natural forest, in a crop field, in a garden or in a vegetable garden.

Preparation time:	Preparation time entails getting acquainted with the equipment to be used. Plan one class period (45 minutes) for this.
Activity time:	The activity can have a duration of several months, if its aim is to investigate the soil respiration change over the seasons running replicates regularly. One replicate needs about 20 minutes.
Application:	Earth science, chemistry, biology
Time for data analysis and discussion:	20 minutes.
Prior knowledge required:	Basic knowledge in chemistry; earth science is appreciated, photosynthesis
Cost:	EGM-1 from PPsystem, Hitchin, UK is provided by the Research Center. Other devices can be used as alternative. About 30€ for Colorimetric Gas Detection Tubes (method taken by USDA Soil kit manual) or a portable (or hand-held) Gas Analyzer for CO_2.
Degree of difficulty:	Medium-High

Materials

- EGM-1 with Soil Respiration Chamber
- Any other Infra Red Gas Analyzer equipped with its own Soil respiration chamber.

Or as an alternative to the EGM-1:

- Cylindrical chamber made of PVC ring
  - (10 cm diameter and 15 cm height)
- Lid to fit the diameter of the chamber with rubber stoppers
- Plastic tube
- Hand sledge and wood block
- Meter stick
- Stopwatch or timer
- Colorimetric Gas Detection tube
- 2 needles and one 150 ml syringe
- Soil thermometer
- Notepad and pen

Procedure

Procedure using EGM-1 (by PPsystem, Hitchin,UK)

The EGM-1 is an Infra Red Gas Analyser, which measures carbon dioxide efflux from the soil. It is equipped with an H_2O filter (it extracts water vapour -IR gas absorber- from the flux of air) and it is connected to the cylindrical chamber (H=15cm; Ø=10cm) placed on the soil just before the measurement starts.

The chamber is placed on the soil and is pressed by hand to avoid external air entrance into the chamber, the gas efflux is pumped and measured automatically by the gas analyzer. An inner automatic fan is installed to ensure a continuous air circulation inside the chamber. This guarantees that a representative flux of gases will be measured. The instrument measures the concentration of CO_2 and it stops the measurement after 120 seconds or a difference of 60 ppm from the initial value is reached.

The instrument measures carbon dioxide concentration (ppm) and efflux of carbon dioxide from the soil (g/m^2hr).

1. Take a patch of earth from the garden or the forest, 10cm deep. Try to keep the sample intact, keeping it compact or, if you can, run the experiment outside, select one or more sites with different characteristics.
2. Remove the litter and cut the vegetation from the spot (approx. Ø=150mm) to avoid measuring leaf respiration.
3. Record the values in a notebook.

Procedure using the alternative method for soil respiration (by USDA: Soil quality test kit guide, 1999. See: http://soils.usda.gov/sqi/assessment/files/test_kit_complete.pdf)

1. Clear the soil surface of vegetation and litter. Drive the ring into the soil using the hand sledge and a wood block to a depth of about 10 cm. If the soil is stony and the ring cannot go deep enough, insert it until you feel resistance from the rocks.
2. Measure the height of the ring in centimetres (take 4 measurements and calculate the average).
3. Cover the ring with the lid and wait exactly 30 minutes.
4. While waiting, prepare the apparatus which will measure the CO_2:
   a. Connect one needle to one end of the plastic tube.
   b. Open both the ends of the Colorimetric Gas Detection tube.
   c. Connect the Colorimetric Gas Detection tube to the other end of the plastic tube.
   d. Take the second plastic tube and connect it to the free end of the Colorimetric Gas Detection tube (the arrow should point away from the needle).
   e. connect the second tube to the syringe.
5. At the 30th minute, insert the needle into the rubber stopper and the second needle into the second stopper to allow the airflow into the head space during the gas sampling. The second needle should be inserted just before the headspace is sampled.
6. Slowly take 100 cc of air into the syringe (1 cc = 1 ml).
7. If the reading is less than 0.5% on the Colorimetric Gas Detection tube, take four additional 100 cc samples of the headspace through the same Colorimetric Gas Detection tube. To do this, disconnect the tube from the syringe to remove the air, and reconnect the tube to the syringe. Take another 100 cc sample.

8. Record the % of CO_2 on the Colorimetric Gas Detection tube: read on the „n=1“ column if 100 cc was sampled or on the „n=5“ column if 500 cc was sampled. The % of CO_2 should be an estimate of the highest point that the purple color can be easily detected.
9. Take the soil temperature close to the ring at the time of sampling. Remove the lid after finishing with the measurements.
10. Calculation:

    Soil respiration (SR) is the amount of gas that comes out from a given area of soil and in a given time interval.

    Pressure Factor (PF) is considered to be 1.

    Temperature Factor (TF) is expressed in °K and is equal to (T (°C) + 273,15) / 273,15.

Δ t = time interval expressed in hours: 30 min = 0.5 hr

Volume above the soil:

chamber area x chamber height (measured with the meterstick)= (10^2 π /4) x (…) = V (cm^3) to be converted in m^3

we need to express the % of CO_2 in g per volume:

n= m / M

Molar mass = 44.01 g

Considering CO_2 as an ideal gas:

1mol occupies a volume of $22{,}47 \times 10^{-3}$ m^3

The grams of CO_2 per volume:

m / V = % CO_2 x ($44{,}01 / 22{,}47 \times 10^{-3}$)

SR =

PF x [(T+ 273,15) / 273,15] x [(%CO_2 - 0.035) x (44,01 g / $22{,}47 \times 10^{-3} m^3$)] x Volume above soil m^3 / [Chamber Area m^2 x (Δ t hr)]

SR= PF x TF x CO_2 (g/m^3) x V (m^3) / A (m^2) x 0,5 (hr) => g / m^2 hr

After the measurements have been taken, soil samples can be analyzed for the estimation of roots and other macro-biomass or other chemical characteristics.

Students run the measurements using EGM-1 in a grass-covered area.

Data comparisons and discussions:

- Create a table to compare the soil respiration in samples with different soil cover/use.

  Different factors produce and promote the efflux of CO_2 from soil: compare soils with different biomass, soil moisture, compaction and texture (worksheets in the library).
- Create another table to compare the concentration of CO_2 coming from the soil and measure the concentration of the gas in the atmosphere.

Sample results already obtained by our students:

15 Jan 2009	CO_2 (ppm)	SR (g CO_2/m^2 hr)
Grass cover	447.2	0.73
Worked soil	473	3.64

Table1. CO_2 concentration and Soil Respiration in the grass covered area and in the area that has been arranged for planting. EGM-1 has been used.

Discussion of results

1. What factors produce CO_2 in the soil and influence its efflux to the atmosphere?
2. What may be the limiting factors for CO_2 efflux?
3. Reflect about land management and land cover. Which ecosystem is most “active” in soil respiration?
4. What can you say about agricultural soils and soil respiration?

Table 1 (data processed by the students) shows a high value for soil respiration at the moment of preparation for planting. The disturbing action changes the soil characteristics such as porosity. It exposes underground fractions to the atmosphere and oxidation reactions and mineralization processes become faster. CO_2 production increases and also soil efflux is facilitated; this result stimulates hypothesis and discussions about agricultural techniques in relation to carbon stocks. In undisturbed conditions soil respiration increases with soil temperature.

DATE	Soil cover	CO_2 (ppm)	S.D.	SR ($g\ CO_2/m^2hr$)	S.D.	RH (%)	S.D.	T(°C)	S.D.
28\11\09	Grasses	482.5	24.82	2.33	1.45	17.9%	0	10.75	0.5
16\01\10	Grasses	411.2	6.13	0.38	0.16	42.5%	0.06	3	0
10\02\10	Grasses	397.5	27.86	0.58	0.57	33%	0.1	3.75	0.5
23\02\10	Grasses	432.5	13.82	0.97	0.19	17.6%	0	8	0
13\03\10	Grasses	467.5	55.65	0.83	0.63	18.1%	0	3	0

Table 2. Example of results obtained during the course of the year 2010 in grass covered soil. Average values and Standard Deviations (S.D.) of CO_2 concentration (CO_2), Soil Respiration (SR), Soil Relative Humidity (RH) and Soil Temperature (T) are reported.

In Table 2 the data processed by the students show a strong decrease of soil CO_2 concentration and respiration in the middle of the winter (February). The low soil temperatures reduce the biological activity influencing the rate of carbon release. During the warmer seasons, the soil relative humidity (excluding the extreme conditions of water saturation or drought) plays a more important role in determining soil respiration.

The CarboSchools library

One of the main tasks that CarboSchools has set out to achieve is to develop and design materials which can be used by teachers and other educators to teach the carbon cycle in the classroom. Hence the CarboSchools library was set up to collate all experiments, protocols, literature and other relevant materials which were developed in the different regional projects.

The CarboSchools regional projects were aimed mainly at upper secondary school pupils, aged 14 - 18. However, many of the experiments developed within the project can be adapted for younger pupils. Some teachers may find it difficult to introduce the Carbon Cycle in class, because they may not have the necessary background in science, or in some cases in mathematics, or experience in working with computers. To overcome this problem, additional reading materials are listed at the end of the experiments to help teachers find relevant literature. Although not a requirement, support from a research institute in terms of scientist involvement can also help prepare the teachers to tackle this barrier.

To facilitate the search for experiments and activities which suit the needs and requirements of the user, the following information was included in each description:

- Preparation time
- Activity time
- Type of activity
- Age of students the experiment was tested on
- Application (curriculum integration or the subjects in which the experiment can be done)
- Time for data analysis and discussions
- Prior knowledge required
- Cost
- Degree of difficulty

Many of the experiments in the CarboSchools library are simple, versatile and flexible. The activities have been tested on students in the given age groups and have been evaluated for their scientific soundness by scientists and for their suitability for use in schools by teachers. A short introduction to the subject matter is added to each experiment description. Each experiment/activity description also includes some tips and suggestions for adapting an activity to different situations. For example, alternative materials and equipment may be suggested in cases where specialised devices are indicated. Some experiment/activity descriptions may contain notes on a teacher's own experience in doing the experiment to aid the user in planning for the activity in his/her own class.

Below is a partial list of experiments, which can be found in the CarboSchools library. For practical purposes, the experiments in the library are classified into 3 categories namely: Indoor- or Outdoor Activities and Working with Data. Within this simple classification, the following experiments can be found:

A. Experiments demonstrating basic properties of carbon dioxide

How to produce CO_2 and test its properties

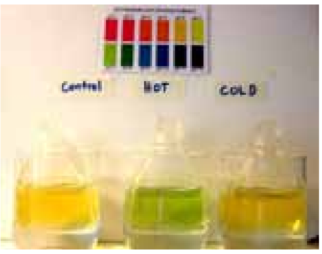
Pupils learn how to produce CO_2 and they perform simple experiments to find out some of its properties.

Greenhouse effect in vitro!

To demonstrate that CO_2 absorbs thermal radiation and is responsible for atmospheric warming.

The greenhouse effect

In this experiment, pupils observe and compare the absorption of thermal radiation by two greenhouse gasses, CO_2 and water vapour.



Interaction at the air-water interface

A set of very simple experiments using cheap and readily available materials to demonstrate gas exchange and equilibration at the boundary layer between air and water. These experiments also introduce ocean acidification.

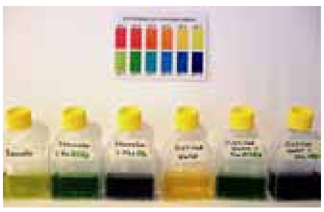
How does temperature affect the solubility of CO_2 in water?

These experiments explore the effects of water temperature on the solubility of CO_2 in water and how this is reflected in a global scale.

B. Experiments showing the behaviour of carbon dioxide in the different "spheres" of the earth

How is global temperature regulated? An experimental representation

Simple experiments to help pupils understand how parameters, like background colour and CO_2-concentrations, regulate temperature at the Earth's surface.



pH-Regulation of seawater: the role of carbonate (CO_3) and bicarbonate (HCO_3)

A simple experiment using a colour indicator showing how the different species of dissolved inorganic carbon regulate the pH of seawater.

Effects of increased CO_2 in the air on seawater and distilled water

In this experiment, pupils compare the effect of increasing atmospheric CO_2 concentrations on seawater and freshwater bodies like lakes and streams. This will give them an insight into the importance of the ocean as a carbon dioxide sink.

The soil breathes

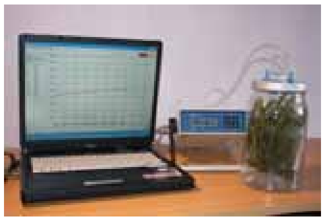
In this activity, 3 different parameters of soils will be measured and their effect on gas diffusion analysed: soil respiration, soil moisture and bulk density. Other activities are also described to determine the role of vegetation, root and soil organisms in the CO_2 flux in the lithosphere.

C. Collection of activities collated from school projects dealing with the carbon cycle

What is the concentration of CO_2 in my classroom?

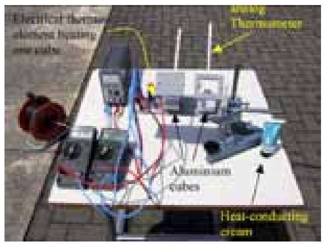
Using a carbon dioxide sensor, pupils measure carbon dioxide concentrations in the classroom and explore what factors can influence this.

A selection of experiments using a carbon dioxide analyser



Examples of demonstration experiments which can be performed in the classroom using a carbon dioxide analyser.

Hands-on experiments for secondary school students



A selection of experiments to motivate teachers and pupils to design their own experiments or to improve some of the presented ones. Most were collected from the experiment archive of the physics division of the Neufeld Gymnasium in Bern, Switzerland.

Collection of experiments on CO_2 and greenhouse effect

Twelve experiments to investigate and demonstrate different aspects of climate change: - physics experiments on radiation and temperature - biological experiments on metabolism (physiology) - chemical experiments on the carbon cycle - chemical-physiological experiment on combustion and metabolism.

D. Experiments showing how biota affects and is affected by CO_2 concentrations

Uptake of carbon dioxide from water by Plants

The following experiments demonstrate the role of plants in mitigating the acidification caused when CO_2 is dissolved in water. This is also a suitable experiment to demonstrate photosynthesis.

Carbon dioxide fertilization of marine microalgae (Dunalliela sp.) cCultures

An experiment designed to illustrate the impact of carbon dioxide on microalgal growth in the aquatic environment.

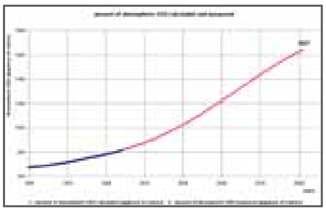
Atmospheric CO_2 can produce ocean acidification

The following experiments demonstrate that high levels of atmospheric CO_2 produce ocean acidification and possible consequences to marine organisms.

Photosynthesis, let's measure it!

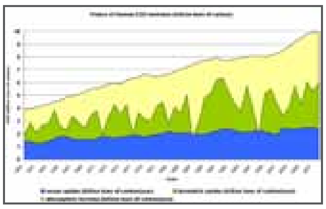
In this activity, students learn some concepts of plant physiology and have a direct and concrete experience of the gas exchanges occurring in the leaf during photosynthesis.

E. Experiments involving use of data acquired from "real" research



Introduction to the principles of climate modelling

Working with real data in spreadsheets to create a climate model, students discover the global carbon budget and make their own predictions for the next century.



Global carbon budget between 1958 and 2008

Working with real global carbon budget data, students produce graphs to find the best representation of the data to make predictions about human CO_2 emissions for the next century. This activity is also a nice application of percentages.

Estimation of natural carbon sinks

Working with real global carbon budget data, students estimate how much of the CO_2 emitted into the atmosphere as a result of human activities is absorbed naturally each year (this activity follows „An Introduction to Climate Modelling" and „Global Carbon Budget between 1958 and 2007").

The following course plans are suggestions to help a teacher organise a Carbon Cycle course. These give a list of experiments and the sequence of when and how they can be done in the classroom. The first course plan was designed for and tested with pupils aged 10-14 years old and requires minimum background knowledge on the carbon cycle. This course will give the pupils the opportunity to get acquainted with the carbon cycle in a "fun" way. The second course plan was designed and used for pupils in the 14-18 age groups.

Example of Carbon Cycle course for pupils aged 10-14 years using the CarboSchools experiments

In most cases, younger pupils will have encountered the term "CO_2" at primary school in association with their own breathing or with plants using it up for photosynthesis. Moreover, as a result of all the information about climate change that pupils are exposed to via different kinds of media (radio, television, magazines, computer games, internet, etc.), they may also be able to associate CO_2 with the present issue of global change. However, for pupils in this age bracket, who have not had chemistry, physics or biology in school, CO_2 is an abstract thing, which they only know from theory. Perhaps they can recite and repeat what they have read or seen on TV and impress their teachers with their "theoretical" knowledge, but seeing it "really happen" in the context of experiments is another issue. The following succession of experiments was designed to help pupils better understand the Carbon Cycle, not ignoring the fact that they will be having "fun" while they are learning.

(Note: Entries in italics are not available in the library, but are described briefly in the table. Experiments/activities in bold letters can be downloaded from the library. The suggested topics are presented in a logical teaching order, but are also flexible and are not in any way dependent on each other. The teacher may opt to do just one of the "spheres" or a combination of any number of them.)

Topic	Rationale	Hrs	Suggested activities/experiments	Expected goals for pupils
Introduction	to orientate the pupils	1	*Question and answer session with pupils; teacher will ask the pupils how much they know about the carbon cycle.* *(Here questions can be formulated by the pupils on what they want to learn.)*	- to form their own questions about what they want to learn - to increase their curiosity about the carbon cycle (teachers will also be able to assess the level of pupils' knowledge on CO_2 as a result of this activity)
What is Carbon dioxide?	to make pupils "see" CO_2	1	*1. Equip pupils with hand-held CO_2 sensors and make them measure CO_2 in different parts of the school.* **2. How to produce CO_2 and test its properties**	- to realise that CO_2 is measurable, that it exists! - to get familiar with the use of the CO_2 sensor - to see that CO_2 concentrations can vary
Influencing CO_2 concentrations	to make pupils realise that they can affect the concentrations of CO_2 around them	4*	**1. What is the concentration of CO_2 in my classroom?**	- to find out what factors can influence the concentration of CO_2 in their surroundings - to get their first experience of a scientific investigation (experimentation, data gathering, data analysis, documentation and presentation of results)
The atmosphere and the Carbon Cycle	to allow pupils to follow and see the consequence of CO_2 emissions going first to the atmosphere	3	**1. Greenhouse effect in vitro** **2. The Greenhouse effect** **3. How is global temperature regulated? An experimental representation.**	- to understand what the "Greenhouse Effect" is all about - to see and really "measure" an increase of temperature when CO_2 concentrations also increase - to find out that other factors can further magnify or decrease this effect

The lithosphere and the Carbon Cycle	to make pupils understand the role of plants and soil in the Carbon Cycle	3	**1. Experiment 8 in: collection of experiments on CO_2 and greenhouse effect** **2. The soil breathes: simpified version**	- to learn about the notion of CO_2 "sources" and "sinks" - to become aware of the importance of vegetation for the cycling of CO_2 -to get a first contact with microbiology; making them understand the important role of bacteria in the carbon cycle
Acids and bases	to gain a rough knowledge of what acids and bases are before studying the hydrosphere	2	*1. Perform the classical red cabbage experiment. Prepare red cabbage juice and use this as an indicator for acids and bases.* *2. Let pupils test the acidity of different substances using pH paper or indicator solutions .* *3. Let students do the same with a pH-meter.*	- to learn how to differentiate acids from bases - to learn how to use indicator solutions, pH paper and pH-Meter - to learn the concept of pH
The hydrosphere and the Carbon Cycle	to introduce the pupils to the importance of the ocean and other bodies of water in the Carbon Cycle	4	**1. Interaction at the air-water interface, parts 1 and 2** **2. Effects of increased CO_2 in the air on seawater and distilled water** **3. How does temperature affect the solubility of CO_2 in water?**	- to understand what happens with CO_2 when it comes in contact with water (oceans and lakes) - to see the consequences of increasing CO_2 in the aquatic environment - to understand the importance of oceans in the Carbon Cycle

Other suggested "fun" activities:

1. Pupils can calculate their CO_2 footprint. If enough computers are available in the school, set aside 1 hour for this activity. There are quite a number of links in the Internet which offer CO_2 calculators.

2. For the "Acid-Base" experiment, pupils can make their own indicator paper. Soak white coffee machine filters or any white filter paper in red cabbage juice for 30 minutes to 1 hour. Let the filter paper dry. Using different substances and different methods of applying, the pupils can create colourful "art work" with acids and bases.

3. Let pupils construct solar cookers and ovens. Instructions are available here: http://solarcooking.wikia.com/wiki/CooKit. Information about other forms of solar cookers are available in the internet. Weather permitting, make a lunch cook-out. The pupils will be proud of their cookers and the hot dog tastes better if cooked in their own cookers.

** the duration of this activity depends on the ideas of the pupils; on what parameters they would like to test. In the CS library the description is for a 1-3 week activity, although the set-up can be made and the measurements can go on automatically without further time investment. The teacher can adjust the duration according to the needs.*

Order of experiments, example for pupils aged 14-18 years using the CarboSchools experiments

This is a suggestion for a sequence of experiments that will give the pupils an overview of the carbon cycle and its relation to global change. The sequence includes some of the activities in this chapter, as well as some from the CarboSchools website, and it can be adapted as required during the year. All entries are available in the library.

Topic	Rationale	Hrs	Suggested activities/experiments	Expected goals for pupils
Temperature evolution	to reflect on Earth surface temperature	1-2	Work on available data of Earth surface temperature from 1850.	- to understand and retain the surface temperature value and its relative evolution
Surface temperature regulation	to explore factors which influence Earth surface temperature regulation	2	How is global temperature regulated? An experimental representation	- to discover that different factors can produce the same temperature effects or that temperature rise and CO_2 rise do not always occur in the same order
Using data to discover the carbon cycle	to work and reflect on real carbon budget data	3	1.Introduction to the principles of climate modelling 2.Global carbon budget from 1958-2008 3. Estimation of natural carbon sinks	- to work on real CO_2 emission data and learn about atmospheric CO_2 concentration and its absorption by natural sinks
Measure CO_2 in different classroom conditions	to get more familiar with CO_2 and the factors that affect CO_2 concentrations.	2	1. What is the concentration of CO_2 in my classroom?	- to learn more about CO_2 in their surroundings
Studying plant and/or ocean carbon cycle regulation *	to carry out more in depth investigations on CO_2 exchanges between the atmosphere and the lithosphere, having gained an understanding of CO_2 sources and sinks between the atmosphere and the lithosphere.	3 hrs for each reservoir	1. Photosynthesis experiments 2. Interaction at the Air-Water Interface, parts 1 and 2 3. Atmospheric CO_2 can produce ocean acidification	- to learn about the role of the different "spheres" of the earth in the carbon cycle - to learn how to write protocols* - to learn how to design their own experiments*
Making predictions for the next century	to wrap up the following questions can be discussed: - Will carbon sinks change? - Will they become more or less efficient? - Will anthropogenic emissions of CO_2 continue to rise? If so, at the same speed?	2	Pupils can now go back to their previous work on the carbon data (activity "Using data to discover the Carbon cycle") and evaluate their predictions for the next century. This is an opportunity for the pupils to revise important facts and to improve the quality of their predictions.	- to use the knowledge acquired from the course in order to better reflect on future scenarios

* Make sure that the pupils have enough time to carry out these activities. Plan time for them to:
- do some background research if necessary
- write their experimental protocols,
- design the experimental set-up,
- carry out their experiments, often more than once
- analyse the results and obtain a conclusion.

Pupils often find writing an experimental protocol a difficult task. They tend to write a few words and then they think it is finished. There are two things you can do to facilitate and improve this step:

- provide the pupils with step-by-step guidelines for writing a protocol
- ask the pupils to write protocols for another group of pupils; the outcome of this exercise is a rise in protocol quality

One of the many posters produced by CarboSchools participants

Chapter 5

"I LIKED IT ALL!" How students appreciate CarboSchools - and what impact it has on them

by Elma Dijkstra and Martin Goedhart
IDO, University of Groningen, the Netherlands

CarboSchools has been a complex project with a large variety of activities carried out at nine locations in seven countries. It is a valuable effort to gather opinions on the projects from students, teachers, scientists and regional coordinators. For this purpose, all students filled in evaluation forms, which we analysed for each regional project. Furthermore, we conducted interviews with teachers, students, scientists and coordinators. It appeared that the students were very positive about the CarboSchools projects. An even more important result is that CarboSchools achieved two of its most important aims: the students were more interested in science careers and they became more aware of the importance of climate change research for society. It is interesting that girls in particular benefited from the projects. Interview data supported the positive evaluation results and highlighted some of the specific benefits and constraints of the projects.

The evaluations reflect personal opinions on the projects. To collect more objective information on the impact of projects we also used attitude questionnaires. This way, we measured changes in the students' feelings towards several aspects of science and the environment during the period that they worked on the projects. Because it is well-known that students' attitudes towards science decline during high school, we were interested to find out if we could positively influence this trend. We found that we did not succeed in achieving this. Attitudes did not change significantly or even declined in some cases. This does not necessarily mean that our initial assumptions on the positive effects of CarboSchools activities on attitudes are wrong. The contrast between the very positive opinions of participating students and this lack of effect on the usual decline in attitudes rather suggests that other experiences, mostly from science lessons in schools, have a more dominant influence on the students' attitudes; compared to CarboSchools projects, which most teachers describe as heavily constrained and limited by timetables, curricula and other structural factors. Nevertheless, although the students' environmental awareness remained unchanged, we found that they improved their knowledge on climate change significantly. Finally, our results show how collaboration between research institutes and schools opens up novel ways to teach science. CarboSchools has only been a start of this development.

Right from the start of CarboSchools, our wish to learn from our projects has been a major consideration. Were outcomes as expected? How do participating actors experience the projects? What were the most important constraints? What do students think of our projects? Can we influence their feelings towards science and climate change? How can we improve our projects? So, CarboSchools is not only aiming at implementing projects as part of school practice, but also at evaluating their effects and identifying their benefits.

Pupils filling in questionnaires at the end of a project.

In this chapter, we will describe how we addressed these questions. We will show that not every student thinks the same about the CarboSchools projects. Some important differences in the students' opinions will be explained. Moreover, we will give some insights into their feelings about science and climate change. Since it is well-known that most teenage students have deep-rooted negative opinions on science and school science, we wished to see whether our projects could influence these opinions. We believe that this evaluation can contribute to research in authentic science teaching and in out-of-school science learning, in the hope that our results can be used by those policymakers and teachers interested in the setting up of a project like CarboSchools.

Box 1: Evaluated CarboSchools projects 2009

Projects	52
Students	1354
- Girls	721
- Boys	622
Student age	12 – 21 years (mean = 16.2)
Schools	60
Research Institutes	8
Countries	6
Time spent on project	1 – 100 hours per student (mean = 36)
Visits to the research institute	0 – 8 per project (mean = 1.0)
Scientists visits to school	0 – 20 per project (mean = 4.4)

Box 2: How do we measure student's opinions on CarboSchools?

We designed a Self-Evaluation Tool (SET) that provided important information for regional coordinators on the benefits and difficulties of each specific project and, regarding CarboSchools, it gave valuable information on the question "What do students think of our projects?". Despite the variety in projects, we developed just one questionnaire for all projects.

The questionnaire consists of three parts. Part A contains 12 questions concerning the student background like age, gender, science grades, interest in science etc. Part B (14 questions) measures student opinions on the science projects and also consists of closed questions in 4-item Likert scales, with options 'strongly disagree', 'disagree', 'agree', and 'strongly agree'. The aspects measured in this part of the questionnaire are: opinions on organisation, appreciation, difficulty, and impact of the regional projects.

An example of a question in part B:
The instructions for the project were clear.

Strongly disagree
Disagree
Agree
Strongly agree

The third part of the questionnaire, part C, consists of 4 essay questions. The regional coordinators can reorganize these questions according to their specific projects. Items in this part may include the students' personal ideas on the project etc. The answer to these questions may help the regional co-ordinator to improve the project.

The questionnaire was translated into all native languages of the students (Norwegian, Catalan, Italian, German, Dutch, French, and English). SET was implemented near the end of a project, no later than one week after the last activities. Additional information about the projects (number of visits to the research institute, amount of time spent on the projects by the students etc.) was provided by the regional coordinator. To get more detailed information we carried out a number of interviews with students, scientists, teachers and regional coordinators. This enabled us to get information on specific local conditions that might influence collaboration between schools and research institutes.

A variety of CarboSchools projects

Most students participating in CarboSchools projects filled in a questionnaire asking for factual information, like their age and gender and their opinions on the projects. These evaluation data provide information for the regional coordinators, helping them to identify constraints and to improve their projects. Furthermore, evaluation data give an insight into the overall appreciation of the projects by the students. In our analysis, we distinguish between different groups, for example boys and girls.

As can be seen in Box 1, we evaluated 52 projects, in which a total number of 60 schools and 1354 students participated. The projects differed in a variety of aspects, such as the age of the students involved, and the number of hours that they spent on the projects. Both one hour experiments or presentations and long-term intensive projects are included in the evaluation. We found many differences in the extent of the collaboration between research institutes and schools: in the vast majority of cases students visited the research institutes at least once, but in some cases considerably more often; and on average scientists visited the schools six times per project, but in some cases up to 20 times.

Further differences (not represented in Box 1) deal with topics, the nature of the projects (open-ended research projects or more standardized classroom experiments), and how the projects were linked to the science curriculum.

Students very positive about CarboSchools

The questions on opinions in the questionnaire can be clustered in four categories: organization, enjoyment, difficulty, and perceived impact of the projects. See Box 3 for the questionnaire items and Box 2 for the set-up of the questionnaire.

Box 3: Students' opinions on CarboSchools

	Strongly disagree	**Disagree**	**Agree**	**Strongly agree**
Question	%	%	%	%
Organization				
This project was well organized.	4	12	50	34
The instructions for the project were clear.	4	18	53	25
The supervisor's explanations helped me to understand this project.	4	13	59	24
My overall opinion on this project is good.	2	10	53	34
Enjoyment				
I enjoyed this project very much.	4	14	58	24
I would like to work on projects like this more often.	7	21	47	25
I like learning science in this way.	4	13	46	37
Difficulty				
This project was too difficult.	21	58	16	4
My knowledge was sufficient to understand this project.	4	21	49	25
Impact				
I learned many new things from this project.	3	14	51	32
This project made me understand that climate change studies are very important for human future.	4	11	42	43
I learned very much from the scientist(s) in this project.	3	17	53	27
This project made me realise that people can affect climate change.	4	14	44	38
This project makes me more interested in choosing a scientific career.	18	36	33	13

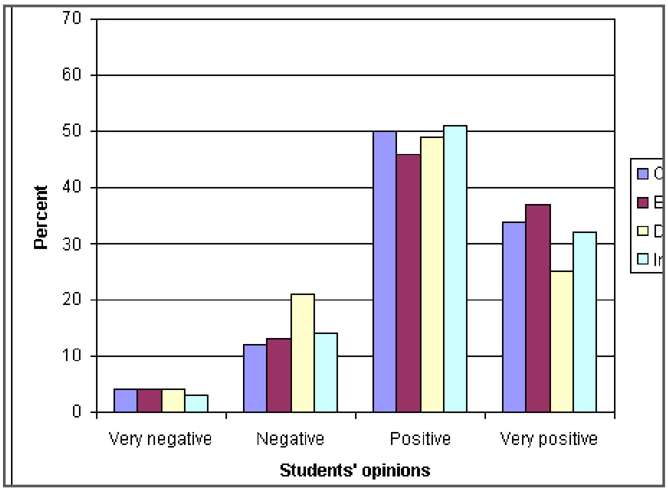


Figure 1: Students' opinions on CarboSchools projects

In Box 3 and Figure 1 we present the evaluation results of all projects. The results show that our students are very positive about participating in a CarboSchools project. A large majority of the students thought the project was well-organized, enjoyed the project very much, realized that people can affect climate change thanks to the project, and would like to work on projects like CarboSchools more often. No differences were found in the appreciation of the projects for short- and long-term projects, but the time spent on the project correlates positively with their perceived impact. In addition, younger students score a bit more positively on all measured aspects than older students. Most students were satisfied with the difficulty of the project, but about a fifth of the students thought that the project was too difficult. Apparently, student appreciation of teaching science in this way is very high.

The projects' positive impacts on student interest in a scientific career and ideas on climate change are worth noticing, especially considering the main aims of CarboSchools. Nearly half of the students (46%) declared that the project made them more interested in choosing a scientific career. We also included some open questions in the questionnaire, allowing students to comment on the projects and thus supporting the positive results of the closed questions. Box 4 shows some examples of the students' comments.

The evaluations also provided information about the students' opinions on science and scientists. It appeared that the students were quite positive about science. Most (at least 70%) of the students are interested in science topics, have high grades on science subjects, do a lot of science at school, and like science lessons more than other lessons. Although

Box 4: What do students think about CarboSchools?

What did you learn during this project?

- The effect of pollution on the ocean, and how important it is to find out more about it (Bergen)
- I now understand better why the oceans are so important for the preservation of our earth (life space) (Kiel)
- How the instruments work, and how scientists do their job (Bergen)
- During this project I learned to work with all my classmates and I learned more about CO_2 in the atmosphere. And we realised that the work of a scientist is interesting and hard sometimes (Barcelona)

What did you like most?

- The presentations in IFM Geomar (Kiel)
- Carrying out experiments and then comparing and drawing conclusions (Paris)
- The interaction with scientists and the research (Barcelona)
- The time we were travelling on the boat (Bergen)
- Scuba diving (Paris)
- Working in a group, and carrying out our own project. And working with scientists, and seeing how they work. It is a different way of working; it is very interesting, a new way (Bordeaux)

What did you dislike most?

- It was a long project and sometimes difficult (Paris)
- The amount of time in this project (Groningen)
- Speaking English (Florence)
- Writing the report was boring (Bergen)
- Not being given the choice of whether I wanted to participate or not (Bordeaux)
- Nothing, I liked it all (Paris)

most students do not think that scientists are boring, a large proportion (45%) thinks scientists are difficult to understand.

As may be expected, students with high science grades and those interested in science tend to have more positive opinions on the projects and vice versa. These students said that they were stimulated to choose a scientific career thanks to the CarboSchools projects. The minority of students with negative feelings towards science also has less positive opinions on the projects, in particular concerning their enjoyment of them. Unfortunately, it seems that the projects do not succeed in convincing these students that CarboSchools is enjoyable.

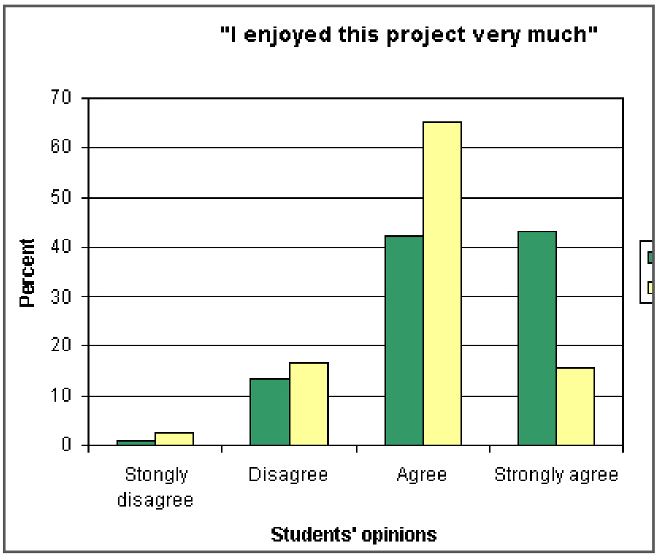


Figure 2: Differences in students' appreciation of CarboSchools projects

Large differences in appreciation were found depending on the initiator of the project, as is shown in Figure 2. Students, who decided to take part in the project themselves, score significantly better on enjoyment, organization, and impact of the project than students of which their science teacher decided to participate in the project. This outcome indicates that motivation could be an important factor influencing students' opinions.

CarboSchools arouses girls' enthusiasm

From research that has been carried out in science education it appears that, in general, boys have more positive opinions on science than girls. Girls' science-related interests are on average more focused on the biological than on the physical sciences. Furthermore, it is known that girls have a more negative image of scientists.

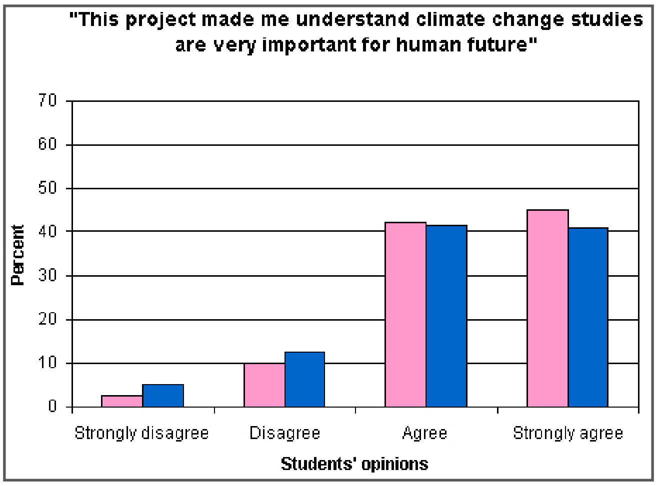


Figure 3: Gender differences in CarboSchools' effect on students' ideas on climate change

These findings from literature are different from our evaluation results, which show that girls are as positive about CarboSchools as boys are. This can be explained by the nature of CarboSchools projects, which are intended to address the relevance of science to society and to create a more cooperative learning environment than that of regular science lessons. From research, we know that these factors appeal more to girls than to boys. As shown in Figure 3, girls are significantly more positive on the relevance of climate change research for the future of mankind than boys. However, our girls find the projects a bit more difficult.

The significance of our evaluation results

As can be seen from the data, CarboSchools students were more positive about science than the average student in Europe. But we should be aware that the teachers and regional coordinators made a pre-selection of students and projects. They had to decide whether the project was appropriate for the students, and whether the students would show enough interest, enthusiasm and would have prior knowledge for the tasks ahead. In some cases, students participating in CarboSchools were volunteers. This means that our students were not chosen randomly and that our findings do not reflect opinions of "average students".

It is tempting to use the evaluation data to compare the projects and to answer the question, 'What works best?' However, we should be cautious in drawing these kind of conclusions. We should be aware that the strength of CarboSchools lies in the fact that each project is developed as a result of a collaboration between a research institute and a particular school, thus its success will depend on that particular group of students, school, teacher and scientist. For this reason, we cannot transfer a successful project from one region to other regions. So, we cannot generalize our findings from one region to other situations.

Science attitudes and career choice

Our evaluations focus on the students' opinions of the CarboSchools projects. These provide valuable information for the regional coordinators and others involved in the organisation of the projects. However, we wanted to obtain a more objective measurement of the impacts of the CarboSchools projects, and we therefore conducted an attitude study. 'Science attitude' is a familiar term in educational research and it is interesting for us, because science attitudes help to steer career choice and school performance.

What do we mean by 'science attitude'? Science attitude is a feeling towards science, for example, an agreement with the statement 'I like science' is an expression of a positive attitude towards science. 'Science attitude' encompasses a number of different components. For this reason, we distinguish between attitudes towards school science, scientists, careers in science and social implications of science (see Box 5 for more detailed information).

The declining interest in science in EU-countries has prompted a considerable amount of research to be carried out into student attitudes towards science. From this research we

Box 5: How do we measure student's attitudes towards science and climate change?

For measuring these changing attitudes we developed the Attitudes Questionnaire (AQ), which is implemented before the project starts and again after the project ends. In this way we can see whether attitudes have changed. The first part contains 12 items concerning general background variables like gender, age, and educational level of parents. The second part contains 39 attitudes statements.

Attitudes Sample Items

Scale	Sample Item
Attitude towards School Science	"Science lessons are fun."
Attitude towards the Social Implications of Science	"Science helps to make life better."
Attitude towards Scientists	"Scientists are less friendly than other people."
Attitude towards a Career in Science	"A job as scientist would be interesting."
Attitudes towards the Urgency of Climate Change	"Climate change is a threat to the world."
Environmental Awareness	"I feel it's important to take good care of the environment."

For measuring attitudes we use Likert's method of summated ratings. That means that a student can choose from the following five responses given for each statement: "Strongly disagree", "Disagree", "Neutral", "Agree", and "Strongly agree". Most of the statements were adopted from existing questionnaires that have been proven to work with pupils. We conducted pilot tests with the instruments and all scales were found to be reliable. All the attitude scales listed were chosen as areas that could possibly be affected by an initiative such as CarboSchools.

The third part is a knowledge test about climate change, which contains 12 items. By measuring this we can see whether knowledge influences the students' attitudes. The climate change knowledge test is presented in Box 6.

We applied a quasi-experimental design. This means that we measured differences between scores on pre- and post-tests without the use of a control group. Both for practical and methodological reasons, the inclusion of control groups that are equivalent to the experimental groups is too difficult in this project. Differences between pre- and post-test and between different groups of students were tested on significance with t-tests and variance analyses to a significance level of $p<0.05$ (two-sided).

know that girls have more negative attitudes towards science than boys. Student age is also important: children at the primary level have rather positive attitudes towards science, whereas attitude scores decline during the secondary school period. This decline is more pronounced for girls than for boys. The sharpest fall occurs for student attitudes towards school science. Experiences in school science between the age of 11 and 14 are crucial in shaping student attitudes and subsequent behaviours in relation to subject choice.

It is interesting that research has shown that high school students have more positive attitudes towards science than towards their science lessons. Some studies have shown that out-of-school science experiences influence student science attitudes in a positive way. This means that we are interested in the question whether CarboSchools projects will alter the trend of declining attitudes towards science.

CarboSchools' impacts on student science attitudes

In a large number of CarboSchools projects we investigated the students' attitudes at two different moments: at the start (pre-test) and soon after the projects (post-test). In this way we are able to see whether the students' attitudes changed significantly over the period that they worked on the project. A difference between pre-test scores and post-test scores is considered statistically significant if it is unlikely to have occurred by chance. In Box 6, we give an overview of the projects in which this questionnaire is implemented.

The results of the pre-test show that students already had positive attitudes towards science before the projects started. All average scores are above "neutral" with scores above 3 (score range 1 – 5; 1 = very negative, 5 = very positive). So, before starting their CarboSchools project, our students had positive attitudes towards school science, the social implications of science, scientists, and careers in science. But not every student thinks and feels the same about science. Can we explain some of the differences we found in the students' attitudes at the pre-test stage? As we can see, high science grades (see Figure 4), highly educated parents, and frequent practical work in science lessons correlate positively to science-related attitudes. Moreover, the younger the students, the more positively they think about school science, scientists, and a career in science (see Figure 5). We do not find any significant differences between the boys' and girls' scores on attitudes.

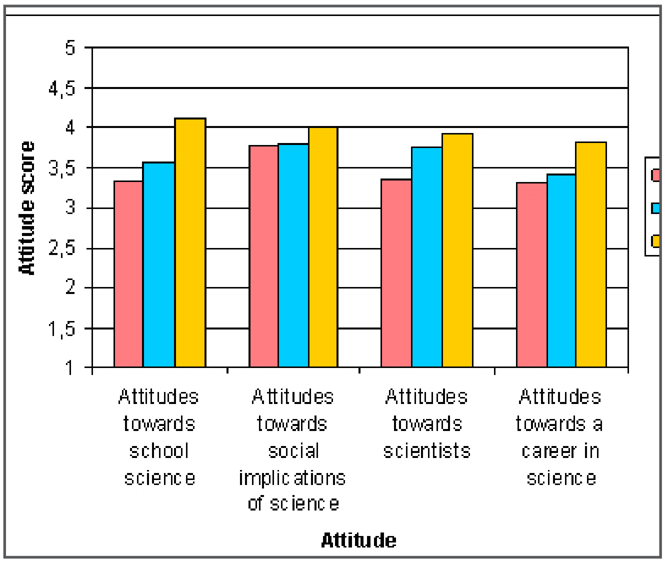


Figure 4: Effect of students' science grades on science attitudes

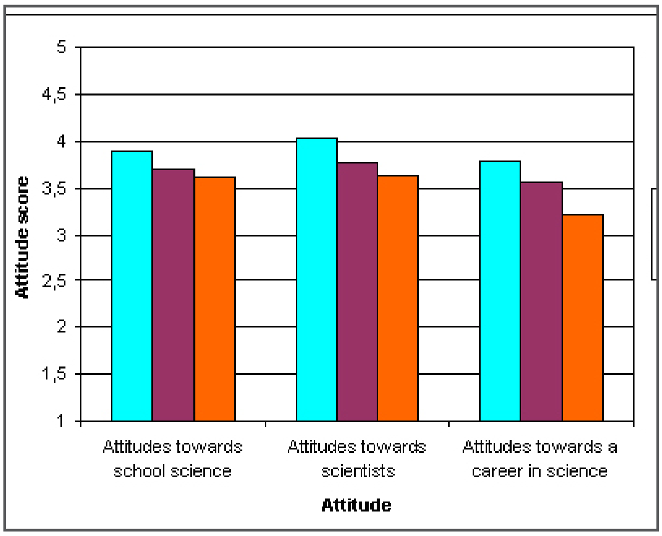


Figure 5: Effect of students' age on science attitudes

From the differences between pre-tests and post-tests we can establish whether the projects affect the students' attitudes. Against our hopes, we found that most science-related attitudes (towards school science, social implications of science, and careers in science) slightly declined after participation in CarboSchools. We found no significant change in attitudes towards scientists for the total group of students, although boys do score significantly lower on attitudes towards scientists after participation than before. An overview of the average attitude scores before and after participation of all students is presented in Figure 6.

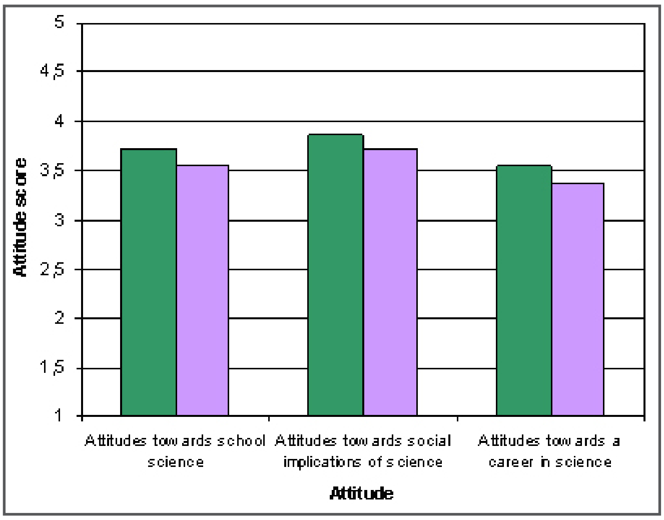


Figure 6: Average science attitudes scores before and after participation in CarboSchools

How can we find positive opinions and declining attitudes at the same time?

It is important to realise that attitudes - measured by external observers - and opinions on the projects - directly expressed by participants themselves - are different categories, which do not necessarily correspond. It is possible that students have positive opinions on the projects, but that their images of science (i.e. their attitude towards science) remain negative. Particularly, this applies to the scale measuring student attitudes towards school science. It is not likely that this will be influenced by our projects, despite the fact that these projects are much appreciated by the students.

We know from literature that attitudes are rather stable - therefore difficult to change by external factors - and they become more negative as teenage students get older. This frequently found decline among high school students is caused by a number of factors; the most important one being probably their experience in science lessons. Despite the positive judgments of the students in CarboSchools projects this trend remains unchanged. An additional reason for finding no improvement in attitudes is that the attitudes of participating students were already at a high level before the projects started; meaning that our student groups did not reflect average student groups.

Box 6: Attitudes Research overview CarboSchools projects 2009-2010

Not all CarboSchools projects were included in our analysis. We included only projects that lasted for a minimum of 10 hours per student, because a certain amount of exposure is needed for changing student attitudes. Furthermore, we excluded those projects with unequal numbers of pre-test and post-test questionnaires. It is important to note that the projects in Bordeaux are overrepresented (10 out of 17 projects).

Projects	17
Students	369
- Girls	200
- Boys	167
Student age	12 – 21 years (mean = 15.6)
Schools	16
Research Institutes	5
Countries	4
Science lessons in a week	1 – 20 hours per student (mean = 6.7)
Time spent on project	22 – 100 hours per student (mean = 59 hours)
Visits to the research institute	0 – 3 per project (mean = 0.5)
Scientists visits to school	0 – 15 per project (mean = 2.0)

One of our most puzzling results is that students express that they are more interested in choosing science careers as a result of the CS projects, while at the same time their attitudes towards science careers actually decline; girls in particular score lower on attitudes towards careers in science after participation than before. Here again we should realise that attitudes and opinions are different categories, which do not necessarily correspond. Students'

Box 7: Climate Change Knowledge Test

		True	False	Don't know
1.	Most of current Climate Change is due to greenhouse gases generated by human activity.			
2.	If my city has a heat wave this summer, it will mean that climate is changing.			
3.	Climate change is only defined as the rising in temperature of the earth's surface.			
4.	Climate change is a result of the ozone layer becoming thinner.			
5.	Climate Change is partly caused by the increase in the emission of heavy metals.			
6.	A rise in sea level and drought are some of the consequences of Climate Change.			
7.	There is a direct link between Climate Change and skin cancer.			
8.	The ocean can absorb CO2 emitted by humans.			
9.	Because of Climate Change, an oxygen deficiency can arise.			
10.	Because of climate change, the water in seas and oceans will expand.			
11.	The acidification of forest is a result of Climate Change.			
12.	Because of climate change, certain plants and animals may become extinct.			

opinions on a science career may be positive, while at the same time their attitudes are negative. This is not a contradiction and can also be explained by the impact of other factors, presumably school experiences.

Student ideas on environment and climate change

We also used the pre-test and post-test questionnaire to find out what students think about the environment and the urgency of climate change (see Box 5). It is expected that participation in CarboSchools projects should influence the students' environmental awareness, their attitudes towards the urgency of climate change, and their knowledge about climate change.

Research literature tells us that attitudes and knowledge influence environmental behaviour. However, knowledge about the environment seems to be an important, but not sufficient, component for responsible environmental behaviour. Therefore, positive attitudes towards the environment are needed. It is known that girls show more concern for the environment than boys. However, male students possess more knowledge about the environment than female students. Our study enables us to get more information on the relationship between knowledge, attitudes and environmental awareness.

Our pre-test results show that students already had positive attitudes towards the urgency of climate change and high environmental awareness before they even started the project. All average scores are above "neutral" (score 3). However, the knowledge test about climate change (see Box 7) seems to be difficult for the students with on average 48 % correct answers.

At the pre-test stage, we found no differences in attitudes towards the urgency of climate change or environmental awareness between students with high, moderate, or low science grades. Knowledge about climate change is not correlated with the students' environmental awareness and attitudes towards the urgency of climate change. We found some interesting differences in the students' opinions: boys score significantly higher on the climate change knowledge test than girls, and younger students have more positive attitudes towards the urgency of climate change and show more environmental awareness than older students, as shown in Figure 7.

The overall results of the post-test show no change in attitude towards the urgency of climate change and environmental awareness, but knowledge of the subject significantly increased: the students chose the 'don't know' option in the knowledge test less often, so it seems students are more confident about their climate change knowledge. Therefore, within CarboSchools, the students' increased knowledge about climate change did not result in changes in a higher feeling of urgency related to climate change nor in a higher level of environmental awareness, as literature describes in other contexts.

Box 8: What do teachers and scientists think about CarboSchools?

Collaboration between teacher and scientist

I think it works well. Of course one of the challenges is that, I have my job, they have their job, and we have to find the time. We have to think, 'okay, now I'm talking to the teacher, who is very busy, so I won't always get the fast response I want'. We are doing our own job and this is something inbetween. But I must say that I am very satisfied with the teachers we have contact with, it's very positive and helpful (RC, Bergen).

In Italy, it is not simple to study with laboratory activites in the school. It is only in the last few years that we have a laboratory, and in the past 3 or 4 years that I have tried to start the program with experimentation. So we have only theoretical lessons, and internet or library research.Very theoretical. I have been teaching for 18 years, so this is a new style for me. Last year, we conducted experiments with CO_2: what is CO_2? what is the effect of CO_2 on ocean, the rocks etc.? And in our school we now have a week of science with an exhibition. So the students love this very much (teacher, Italy).

When they go on the site visits, it really depends on the teachers what they do. Some teachers are really well prepared and want their pupils to do special activities and they organise it well with me and the scientist concerned. In this case, the visits have a more positive feedback from the students than when the teachers just leave it to the scientist to give a tour (RC, Bordeaux).

Scientists are very easy going. In Norway the distance between scientists and other people is not very big, and nor is that between teachers and students. There is no authority gap as in most other countries, which has an affect on their contact. You don't feel inferior to the scientists. When the scientists go to school, it's just another person going to school. They are not afraid to ask questions, etc. (teacher, Bergen).

A collaboration between a teacher and a scientist is very useful, because the topic is very up -to-date, as is the scientist. And the students can meet scientists, which gives some weight to the project (teacher, Paris).

Scientists working with students

One scientist is a friend of mine, but the others are not, 5 different scientists. Very valuable with the students (...) The contact is very easy with them. They want to show their work, and show it is interesting. For me the problem is that they are very busy (teacher, Bordeaux).

I think it can give scientists a new vision. For example, after the final conference, all the scientists said that they had not imagined that pupils could get so far with the carbon cycle. They were very surprised by what the teachers and pupils achieved. So I think it changed the view they have about teachers and pupils (RC, Paris).

I'm happy when the pupils run measurements. Let them know what we really do in the office and in the field. Bring the science to the students. Knowledge of students is a second goal (RC, Florence).

It has been stimulating working and communicating with teenagers (RC, Bergen).

I learned what kind of activity can work with pupils. For example they can work with the Excel file. They can do some calculations. They can measure CO_2. But this project is too long. It is difficult to conduct projects for more than three months. Pupils want to change topics. And I learned it is difficult for them to retain what they have learned, because they do other things. I think that scientists forget these things. They speak and one week after they think the pupils know it (RC, Paris).

What did we learn?

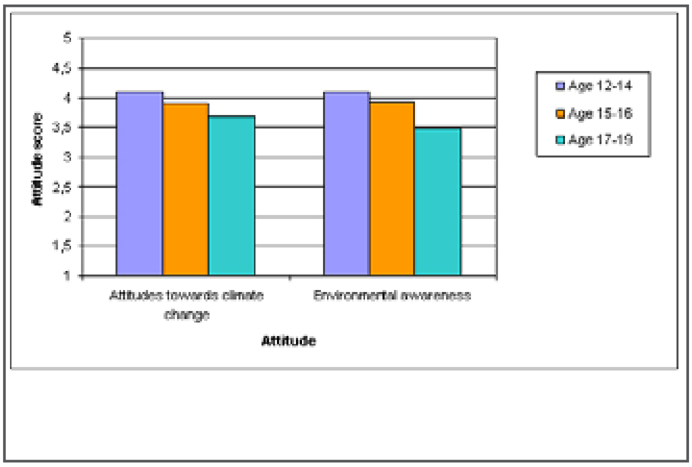


Figure 7: Effect of students' age on attitudes towards climate change and environmental awareness

So to summarise: students evaluated all projects positively. The results of the attitudes research show that our students in all regions have high environmental awareness and very positive attitudes towards several aspects of science and climate change, but that despite their positive experience of CarboSchools, these attitudes follow the usual decline observed during teenage.

These findings do not mean that attitudes decline because of CarboSchools activities, i.e. that hands-on experiments and scientist involvement in schools influence attitudes negatively while, on the other hand, they are applauded by students. What they do indicate is that the proportion, duration and scope of these activities with respect to daily classroom activities (and broader external factors) have been insufficient to counteract the mainstream effect.

We can particularly assert this from additional information we obtained from our interviews with students, teachers, scientists and regional coordinators (see Boxes 4 and 8). Interviews with students supported the results from the written evaluations. In the interviews, teachers and scientists commented positively on the projects. One of the impacts some of the

Box 9 - Some obstacles to CarboSchools activities reported by participating teachers

- Time to dedicate to projects is just voluntary work and necessarily very limited (in our curricula extra projects are not considered).

- Our headmasters do not sustain these projects and individual ideas; they're more interested in general programs about school and administrators.

- The class colleagues are not very helpful with us or with the students (perhaps envious?).

- Problems finding money, raising funds, finding sponsors.

- Difficulties to getting agreements from administration for trips, days out, etc. You must ask permission for everything and all activities, all materials need supervision. This makes it difficult because you have to explain everything again and again.

- Problem of time schedule given by the headmaster to the teacher who runs such a project, for example the teacher may need two or three hours in a row, but will not get it.

- Student hours: There are very strict rules about how many hours every student needs in every subject. That means that it might be hard to take the students out from other classes to do, for instance, field work for a whole day. Most of the time, it is possible to get by if it's only 2-3 days over a whole school year, but it is impossible to have specific tasks that need to be done every third week.

- Collaboration with colleagues: most teachers can find teachers to collaborate with, but it is hard to find time to do the collaboration. We have a lot of common meetings that are filled with tasks for larger groups, and even though we ask for time to do collaboration between teachers who either teach the same subject or who want to discuss their subjects, there is always a long „waiting list" due to all the other „more important stuff" they want to fill the meetings with.

- Not all pupils are very motivated; a lot of them are actually not. And if I want to do a project like this, I need to include the whole class, otherwise it will be something that I do in my free time and the pupils' free time. This means that the project must be easy to implement within the curriculum.

(statements written by teachers during a session dedicated to structural obstacles at the project's spring school in Jena, April 2010) interviewees referred to is the collaboration between schools and research institutes, and between scientists and teachers. This is a valuable result, which can have a big impact on the way science is taught in high schools. Expanding this kind of teacher-scientist-partnerships to regional and national levels will influence science curricula to a large extent. It will bridge gaps between school science and real science, and this may have positive effects on students' school and career choices.

However, the interviewees also identified many constraints. From the scientists' side the lack of time was mentioned as a constraint and they had the feeling that their efforts in outreach activities with schools were not always valued by their superiors. Teachers pointed out that external projects are difficult to implement in the school curriculum. Schedules have to be adapted, which is not easy, and often, a lack of time and money plays a role here. Rules and standards for students and teachers may interfere with the project's implementation within the school curriculum. Moreover, extracurricular activities, such as those offered by CarboSchools, may not be attractive for students who do not want to spend more time on school activities. School authorities did not always support the participation of schools in CarboSchools (see Box 9).

Altogether, developing project-based, hands-on activities with scientist involvement currently remain a real challenge in highly constrained school systems. This shows the limits of such experiences within the existing school systems and their dominant culture. CarboSchools illustrates once more, as practitioners of ESD report everywhere, that to fulfil their promises (and subsequently to reach a large number of teachers) such activities should not be offered as an additional component to existing overloaded curricula and timetables, but should be properly integrated, thus requiring profound changes in the whole education system.

The personal contact between the students and scientists, the relevance of the issues addressed in the CarboSchools projects, the inquiry-based pedagogy used in some projects, and finally, the use of group work all gave students a new and very positive experience in science. CarboSchools has shown to students that science is different to what they experience at school and can actually be interesting and important for their future, both as workers and citizens.

Third CarboSchools Educational Booklet

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A 5th grade class measuring the CO_2 concentration in their classroom with a CO_2 sensor learned about how high concentrations of CO_2 can affect them. The following day, their Math teacher arrived in class and all the pupils were jogging in place or hyperventilating. When she asked the children what the matter was, they answered: „We want to reach 5000 ppm of CO_2 in the classroom, then we will be sleepy and cannot concentrate.... we won't have to write the Maths test!"

- Education is what remains after one has forgotten everything he learned in school - A. Einstein

CarboSchools links researchers from several leading carbon science laboratories with secondary schools. In these partnerships, young Europeans conduct experiments on the impact of greenhouse gases and learn about climate research and the reduction of emissions. Scientists and teachers co-operate over several months to give young people practical experience of research through true investigations, interactions with real scientists and public presentations.

From January 2008 to December 2010, nine research institutes in seven countries explored how they can best motivate, initiate and support such partnerships at the regional level across a wide variety of contexts, topics and age-groups. European co-operation made it possible to compare results, learn from each other and develop replicable good practice. In total, more than 90 schools have been involved in this „educational laboratory", exploring a whole range of experiments & project activities, evaluating them and publishing them on the project's on-line library of resources.

This book is the legacy of this educational experiment to the broader educational community in Europe and beyond. It gives interested teachers concrete ideas and advice to make science learning more engaging, challenging and attractive, and to encourage pupils to experience their global impact on the Earth system and how they can help restore the balance.

Youth sharing the responsibility for a sustainable environment
Pupils with a mussel pole for collecting specimens for their experiment

UN DECADE OF EDUCATION FOR SUSTAINABLE DEVELOPMENT
DÉCENNIE DES N.U. POUR L'ÉDUCATION EN VUE DU DÉVELOPPEMENT DURABLE
2005-2014

CarboSchools and this publication are a contribution to the United nations Decade of Education for Sustainable Development