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Sustainable Development in Science Education

PEDAGOGICAL APPROACHES AND STUDENTS' OWN INQUIRIES

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This practical guide helps chemistry teachers to plan their teaching from the perspective of sustainable development, and to integrate mathematics into their topics. The theory in the beginning of the guide and most of the ideas for inquiry-based activities are from the doctoral dissertation "Holistic and Inquiry-based Education for Sustainable Development in Chemistry" by Juntunen (2015).

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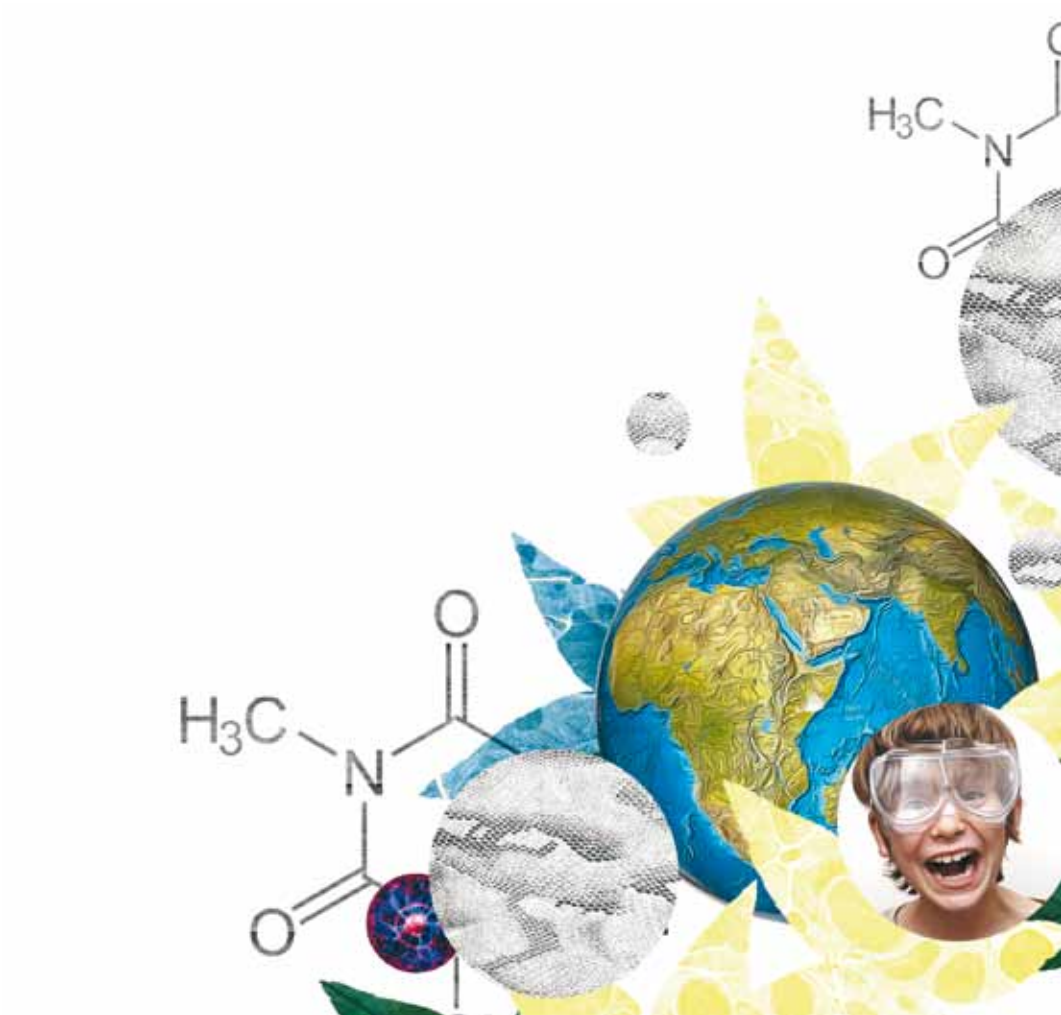
What educational topic

COULD BE MORE IMPORTANT THAN THE QUALITY AND SUFFICIENCY OF NATURAL RESOURCES ON THE EARTH?

COULD IT BE POSSIBLE TO SOLVE THESE CHALLENGES AND CREATE SUSTAINABLE WELFARE FOR EVERYONE WITH THE HELP OF CHEMISTRY AND MATHEMATICS?



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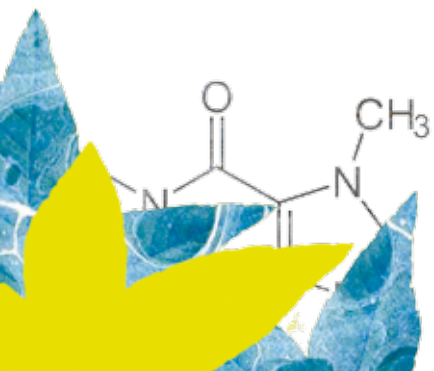


Holistic chemistry education inspires everyone

Would you like take part in building a field of chemistry that helps to solve the biggest problems of mankind? You are needed! Teaching methods and topics in chemistry can be reformed at all levels of education to support sustainable development.

The modern teaching of chemistry is holistic and focused on environmental and responsibility education. The ideas in this guide are based on student-centered, interdisciplinary and inquiry-based teaching methods. When it comes to different teaching topics, chemistry education is more controversial than ever before. The field of chemistry creates welfare and provides solutions to our problems, but also produces great problems that we are not able to solve for the time being. Inspiring teaching of chemistry takes both of these sides into consideration.

Our materialistic standard of living relies mainly on fossil-based resources. At the same time we cause rapid changes in ecosystems on Earth. The challenges as well as the solutions are, for the most part, chemistry. Come along on a journey to reform chemistry education.

Even though chemistry teachers seem to be willing to include sustainable development in their teaching, it has been quite limited so far. Discussions on the different ways citizens can influence the future of the Earth are rather infrequent in chemistry classes. Only few students associate the meaning of science with contamination of ecosystems or moral issues. There are many reasons for this: some teachers feel they don't possess sufficient theoretical knowledge on sustainable development and the pedagogical approaches related to it. Also, some feel that the required lesson preparations are too time-consuming, the students can't work in peace or there's is a lack of suitable exercises, time or collegial support.

Partly due to the current teaching methods, students consider chemistry to be a difficult subject that is irrelevant to their everyday life. Fortunately, this image can be changed to a more positive one with the help of new topics and teaching methods. At the same time we can obtain a better understanding of the chemistry related to changing ecosystems and the necessary solutions.

The new Finnish national core curriculum, strategies of education and chemical industry as well as latest research findings require that chemistry education should be made more inquiry-based and focused on sustainable development. This guide attempts to answer some of the practical questions concerning this change. How to include different types of activities related to sustainable development in your chemistry teaching throughout the school year?

Our experiences in school have an effect on our interests and environmental literacy. Participating in inspiring, hands-on work for the environment creates more positive attitudes towards nature. Personally significant experiences and knowledge on environmental issues are in the key position.

Teaching that attempts to empower students and encourage active citizenship should include:

- solving problems together
- consideration of different viewpoints
- practising argumentation skills
- student-centered, inquiry based and inspiring teaching methods.
- critical contemplation of prevailing norms
- discussions on local and global values
- informal education and out-of-school learning

(e.g. field trips and visitors)

- engaging the youth in communal decision-making

cross-curricular approaches

Education for sustainable development includes both theoretical knowledge of chemistry and citizenship skills. If the themes in chemistry education are familiar to the students from their everyday lives, studying becomes more meaningful and the theory easier to learn. The objective is that the students aks questions and retrieve information on their own initiative. The skills of scientific argumentation and making conclusions can be practiced with the help of examples. Conflicting views that emerge can provoke ethical thinking. In this way, teaching supports students' environmental literacy and ability to evaluate different statements.

This guide attempts to encourage teachers to adopt inquiry-based and student-centered methods for teaching sustainable development. The guide is based on the socio-constructivist learning theories. The ideas introduced in this guide are suitable for all learners, but especially students (for example girls, scientific minded students and those with challenging background) who need more creative teaching methods benefit from these ideas. The starting point of the guide is the expertise of chemistry teachers, who are both chemists and pedagogs. They understand the need to constantly develop chemistry education and the field in general, in order for it to better meet the needs of today's society. The role of education for sustainable development in chemistry classes depends on the teacher. Together we can change the culture – step by step!

The state of the world and chemistry of changing environment

Sustainable development in chemistry education includes themes such as the state of the Earth, our everyday life and green chemistry. These themes help students to see the connection between the school chemistry and their everyday lives.

Education for sustainable development is cross-curricular, in other words interdisciplinary*. In addition to knowledge of chemistry, the themes also include ecological, economical and socio-cultural aspects. Thus, understanding the overall picture requires complex and holistic interdisciplinary understanding, or systems thinking. To a certain degree, it is possible for children as well.

Green chemistry is a branch of chemistry that aims to minimize the amount of waste, promote the use of safe chemicals as well as save energy and materials. These topics enable the teaching of a wide range of knowledge and skills, as well as discussion on different attitudes and values. Theoretical teaching can be divided into three categories:

- knowledge on environmental problems
- knowledge on socio-cultural causal connections
- knowledge on alternative courses of action and possible solutions

Teachers of chemistry have suggested that topics related to the state of the Earth and study modules planned in cooperation with the students should be included in the chemistry education. Some teachers have already included topics related to sustainable development* in their teaching, and these topics are listed in Table 1.

Table 1. Topics of sustainable development that teachers use in chemistry education.

Soil Chemistry of different types of arable land and cycle of fertilizer, acidification, pollution, chemistry of healthy soil
Water Water quality, sufficiency and treatment (water resource management). Change, contamination, acidification and chemicalization of aquatic ecosystems
Air Atmospheric changes, ozone depletion, local air quality (indoor and outdoor) and how to measure it, particulate matter
Species and genetics Epigenetics (studies chemicals that affect the genotype and cause cross-generational diseases)
Natural resources Fossil fuels vs. sources of renewable energy and material, Ecosystem services, mining industry, circular economy, natural resources, hazardous waste, recycling, life cycle of products

***For more information, search for "interdisciplinary learning" or watch a Youtube video called "Project based learning: Explained".**

***In addition to the theory, chemistry teaching can also include discussions on different perspectives on welfare, environmental problems near the school, the state of the world, human and animal rights, economic stability, protection of nature or view the present situation from the viewpoint of the history of civilization.**

Table 2 summarizes the aspects of chemicalization. According to Nature, a prestigious scientific journal, the phenomenon is for the most part unknown to the public, but poses a global threat as serious as global warming. It is difficult to study the long-term effects of the interaction of different chemicals in ecosystems. Questions concerning chemicalization: How are environmental samples examined? What are the solutions to stop chemicalization?

Table 2. Summary of topics related to chemicalization:
Chemical substances affecting ecosystems, different types of pollution sources, effects on ecosystems and health risks. More information on potentially harmful substances and chemical safety guide on: http://www.tukes.fi/en/Branches/Chemicals-biocides-plant-protection-products/Industrial-and-consumer-chemicals/

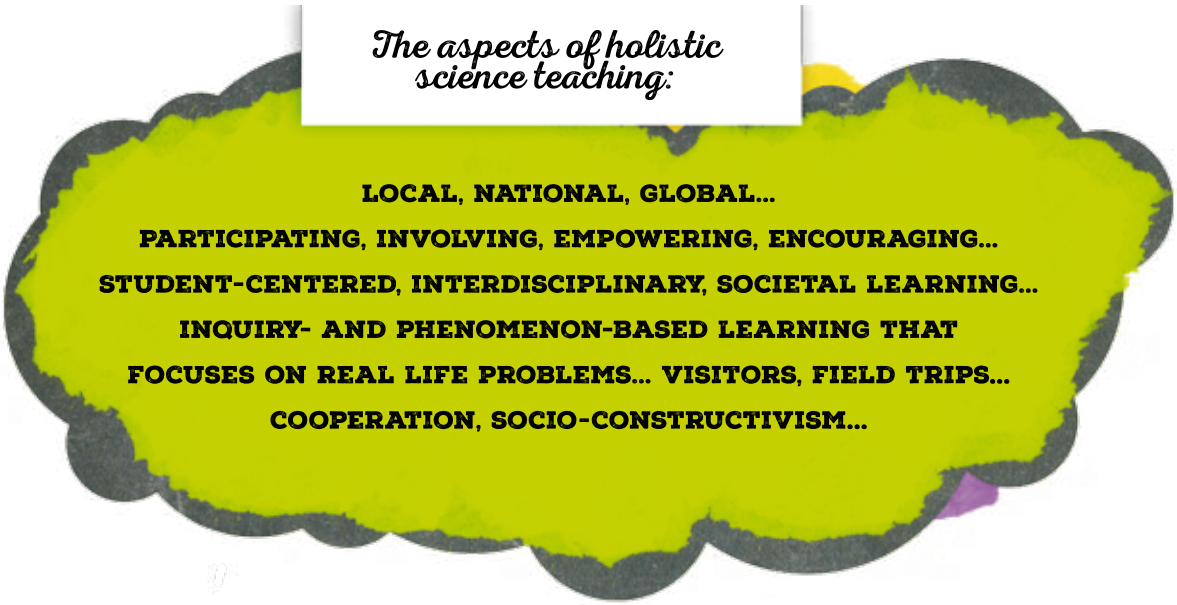
Substances affecting the hydro-, geo-, atmos- and biosphere:
Asbestos, biocides, CMR-substances, dioxins, inorganic gases (COx, SOx, NOx, N2O, HFC, PFC, SF6), formaldehyde, furan, halogenated hydrocarbons (PCBt, CFCt, PFCt), allergens (nickel), air particulates that affect hormonal action (VOC, PM, NMVOC), pesticides, medicaments, methane, plasticizers (PBA, phthalates), organically bound metals, PAH chemicals, detergents, fuel spills, PBT and vPvB substances (Persistent, Bioaccumulative and/or Toxic), radioactive substances, heavy metals, photochemically active hydrocarbons

The effects on ecosystems include:
Bioaccumulative substances in the food chain, garbage pollution (plastics), changes in smell, taste and colour, oxygen depletion (H2S), diversity loss (some species are sensitive to e.g. pesticides or changes in pH), changes in pH, eutrophication, salting

Health risks can be:
Acute or chronic, affecting individuals, species or the whole community

Different types of pollution sources: Point pollution (industrial waste, cities), nonpoint pollution (agriculture, animal husbandry), fallout (burning processes) and natural leaching (in acidic conditions, e.g. dilution of aluminium and heavy metals)

Effects are related to:
Harmless carrying of bioaccumulative substances, metabolism of organs, decrease in diversity, hormonal action, tumours, growth, mortality, behaviour, reproduction, genotype, diseases



Inquiry-based education for sustainable development requires tolerance to uncertainty and courage to seek answers to unanswered questions – together with the students. The themes differ from those of the traditional teaching of chemistry by being multidisciplinary, presenting conflicting viewpoints of different interest groups and involving information that is constantly changing. However, these issues don't need to be solved with the help of teaching, argumentation, logic or research results. These types of topics and inquiry-based methods help the students to improve their systems thinking skills. A student learns how to study a complex environmental problem: to look at the cause, spreading and possible solutions – and connect it with their knowledge of chemistry. Global environmental problems can sometimes be difficult to comprehend as they are usually not visible in our daily lives.

We are all responsible educators* and our pedagogical choices are important. Ethical issues in chemistry can be brought up by, for example, presenting questions that don't have right answers, such as: What are the goals of sustainable development? Is it possible to achieve these goals and attain environmental, economical and cultural well-being at the same time? How does the technology and products we have developed affect the diversity of nature? What about human welfare? Should the influence of large global enterprises be limited?

***Reflection for teachers: Does science rely too much on technological solutions when it comes to environmental problems? Do the solutions require admitting conflicts of interest? The western standard of living and consumer society relies mainly on underpriced raw material imported from the south, which again leads to massive environmental problems and human right violations. Do the political leaders belittle citizens who stand up for nature conservation?**

Finding solutions through own inquiries

When choosing teaching methods and topics, the focus should be on students' questions, interests and opinions. When it comes to teaching methods in chemistry, the students have expressed a wish for more videos and animations, information retrieval, field trips and visitors as well as project-based learning. All of the aforementioned methods are still rather uncommon in chemistry education. Also summaries, essay writing, teaching material made by the students and comparative studies are examples of rarely used methods.

The teacher can also show a list of different types of methods to the students and let them have a vote on which teaching methods should be included in the course.

TAKING NOTES
READING
DOING EXPERIMENTS
OWN RESEARCH PROJECT
INFORMATION RETRIEVAL
VIDEO
PEER LEARNING
DEBATE
PLAY
GAME
COMPETITION
QUIZZES
STRUCTURED DISCUSSION
POSTER (EXHIBITION)
NEWSPAPER OPINION PIECE
ARTICLE

INTERVIEW
PORTFOLIO
ESSAY
FIELD TRIP
STUDYING OUTSIDE
STUDENTS' OWN EXAM QUESTIONS
A TAKE-HOME EXAM
SPOT CHECK
LEARNING DIARY
WRITTEN EXAM
ORAL EXAM

In chemistry, the objective of education for sustainable development is to improve students' investigation and action skills. They can be both quantitative (e.g. solutions for reducing consumption or emissions) and qualitative (e.g. critical evaluation of information in old textbooks and online, as well as skills of co-operation, decision-making and initiative). The education for sustainable development can be divided into three categories:

* Experiences in authentic environments
* Theoretical knowledge of chemistry with regard to sustainable development
* Attitudes and skills to contribute to sustainable development, also by using chemistry

Values* and civics education should encourage the students to make decisions that help them to find answers to contradictory questions or the best alternative course of action – based on scientific knowledge. The students can be asked to form their own research questions. Here are some example questions:

At an individual level:

• How does the product I use affect the environment?

• Which is a better choice: tap water or bottled water?

At societal level:

• Are there better choices available in the market?

• How is the energy supply of our community secured in the future?

At a global level:

• How does the product certification promote sustainable development?

• Why do different countries use different amounts of natural resources?

Chemistry education relates to the society through teaching methods that:

• Consider solutions to real-life socio-scientific issues.

• Take advantage of interdisciplinary cooperation between teachers of different subjects.

• Involve reasoning, argumentation and decision-making based on scientific knowledge.

• Apply inquiry-based learning methods, e.g. student-centered knowledge building and peer learning.

• Apply collaborative, social and emotionally engaging learning methods, e.g. project work and role-play debates.

• Welcome representatives of different interest groups to the lessons.

• Take advantage of local outdoor environment, for example in the form of field trips.

Take a look at some new innovations together with the students. When doing this, note that sustainable development innovations and also older related technologies are typically linked with ethical issues and conflicts of interest between separate groups. These differences stem from the way information is interpreted or from differing values. There is a constant societal battle for definitions* concerning the nature of the problems, different approaches and solutions.

Inquiry-based approaches are suitable for education for sustainable development because they give the students an opportunity to express their personal opinions and ideas. And even though open and project-based learning methods may seem demanding at first, they are also meaningful and highly motivating to students.

The difficulty of inquiry-based methods depends on the openness of the task:

• At the basic level, the research questions and methods are given to the students, but the results of their observations are formula-

***In Europe, the core values for sustainable development are politically accepted across party lines – freedom and responsibility, ecological integrity and diversity, human interdependence, democracy, nonviolence and peace.**
***An example of a battle of definitions is the debate on which shopping bag is the most ecological. There is no one truth. The number of instances of use and the contents of the bag are more important than its material, the packaging of the products or transportation. The shoppings that are disposable, energy and resource intensive or unrecyclable should be avoided. Also the mode of transportation used by the individual shopper can be a significant factor in the environmental effect of the shoppings.**

Table 3. Example questions for the teacher:

Facts, values, attitudes and alternatives regarding the information	**Reliability of the information**	**Expertise and scientific knowledge**
Is the statement based on research, values or so-called "alternative facts"? What are the most important values to the authors? And to you? Are there any other alternatives you can think of? What advantages and disadvantages do these alternatives have?	What is the source of the information? Is the source reliable? How was the information gathered? What is the motive for publishing the information? Is it their area of expertise? Does the scientific community agree with this information?	Are there any statements in the text that arouse suspicions? Can you explain a scientific term based on the text? What would happen if we didn't take notice of the thoughts of specialists? What is required in order to the prediction to come true?

ted by the students themselves.

• At the intermediate level, the research questions are given to the students but they are supposed to come up with both the suitable methods and results.

• At the advanced level, the students are also supposed to formulate the research questions by themselves.

Teacher's role is to be a consult posing questions and a friendly critic who directs the inquiry-based activities towards students' own interests and scientific questions that they want to find an answer to (so-called interdisciplinary learning). Using suitable approaches, the teacher can help the students to improve their multiliteracy and critical thinking skills. New knowledge is acquired by asking questions. To support question-based teaching, we have gathered some example questions in Table 3. At first you can use only a few questions and later expand the point of view. It is important to emphasize to your students that this type of speculation is part of a scientific research process. The students should also be aware of how these skills are assessed.

Topics of environmental chemistry can be integrated into almost any school subject. Unfortunately, this type of integration is still rather uncommon. Biology has been the most common subject to be integrated with chemistry, and the most common interdisciplinary theme has been water. Different inquiry-based interdisciplinary approaches are gathered in Table 4. For example primary school teachers use at least three different inquiry-based approaches: stimulation of senses, problem-solving and using students' own questions.

Inquiry-based learning has shown to increase students' motivation and interest to learn more, especially when it comes to girls and students with challenging background. The approach promotes active participation, inner motivation, boosts self-confidence and positive self-image as a learner of chemistry as well as develops higher order thinking skills. This is based on the fact that the inquiry-based methods allow the students to:

• Make choices regarding their studies (autonomy)

• Feel successful (competence)

• Cooperate with their classmates (sense of solidarity and participation)

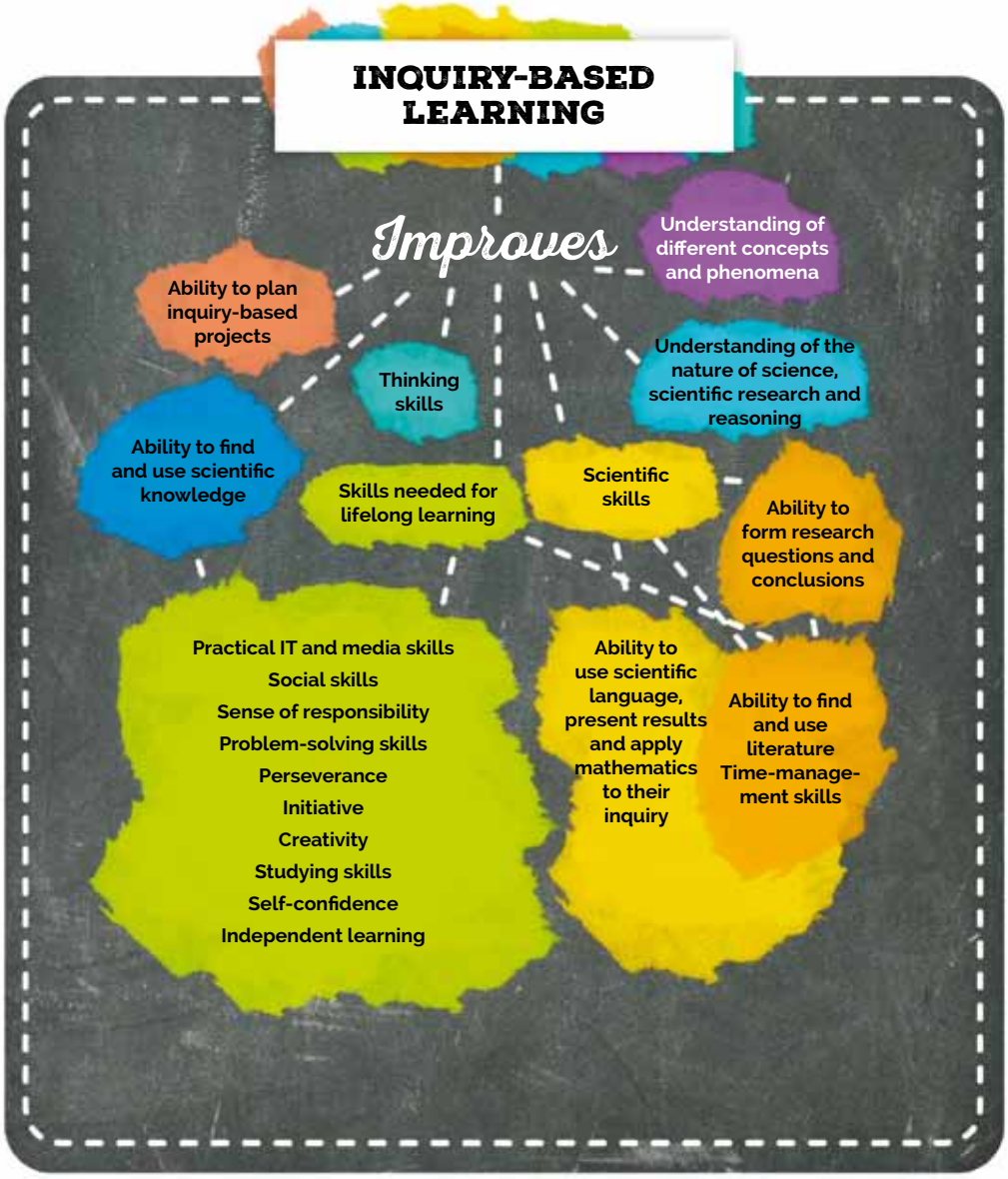


Table 4. Ideas for inquiry-based teaching methods in chemistry

Mini-posters
The teacher shows a list of links to websites about sustainable development* and gives the students an hour to prepare a poster about one of the topics related to chemistry. The posters are then hung in the hallway and the students get to practise their presentations for a moment. During the break, other students and teachers are invited as an audience to a light-hearted science conference.

Question Board
The students get to write any questions they can think of to a separate question board, anytime they want. In addition to that, there can be a separate time for searching for more interesting questions or problems that could be tested. This helps the students to pose questions that can be examined scientifically.

Open research
When discussing food stuff chemistry, the teacher asks if the students have any questions related to drinks or food. Then in small groups, the students think of questions and do some examinations and observations concerning some of them. Finally, all groups present their questions, methods and observations to others. Same type of approach can also be applied to topics such as elements or surface tension.

*More suitable topics on the last page of this guide.

Table 5. Means of promoting environmental awareness (after Salonen, 2010, 146)

Pushing towards sustainable development if students	Pulls towards sustainable development, when the teacher catalyzes
Feel anxiety about the future	Confidence in safety and solidarity in the future
Are worried that the measures taken are not enough to avoid environmental crisis	Ethical actions, taking responsibility of others, nature and future
Are afraid of the consequences that the future crisis may have for their freedom of choice.	Possibilities to join communities, politics and culture
Take a critical view of prevailing culture and gradually become estranged from it	Pursuit of purpose and meaning
Are stressed because of the current way of life	Investing time in self-education and improving the human-nature relations

Environmental literacy is interdisciplinary, and in its broad sense, it is close to the concept of scientific culture. The teachers can support the environmental literacy of their students in many ways. For instance significant personal experiences and knowledge on environmental issues create more positive attitudes towards protecting nature. Good self-esteem, optimism and belonging to a community increase active caring for the environment. Also, feeling able to influence and control what happens around you has been noted to increase eco-friendly behaviour. Table 5 introduces concrete ways of influencing students' views on sustainable development.

Activity that is motivated by environmental awareness emphasizes two aspects in particular: problem-solving and individuals' own choices. Active participation creates emotional experiences and helps the students learn how to set their own goals. The whole community can be engaged in these eco-conscious actions. A good example of this is the "Eco Schools" -programme that involves the students in planning and carrying out ideas that make the school environment more sustainable.

It is important to make sure that the practises and behaviour of the adults in school are consistent with the teaching. If, for instance, the students are taught to recycle and favor vegan food but the

*** Teacher's own attitudes and knowledge on environmental issues usually correlates with her/his role in promoting sustainability in the classroom. Characteristics of a good environmental educator include environmental sensitivity, moral responsibility and independence, ability to critically evaluate one's own behaviour and culture, awareness of the societal power relations as well as capability and willingness to act for the benefit of the environment.**

school culture contradicts this, it may have, according to some studies, a rather negative influence on students' attitudes.

The relationship between attitudes and action is always more or less inconsistent. Human behaviour is often situational: some of it is conscious, based on knowledge and rules, whereas some of it is less-conscious, based on skills and know-how. Students' responsible environmental behaviour is mostly based on routines since they are only learning new things and because the school culture is often based on rules. Environmental education in schools is often focused on cognitive teaching methods that attempt to change the human behaviour by informing the students about the effects of their choices and even by moralizing. However, increasing awareness and knowledge on its own is usually not enough to cause real change in behaviour.

A short project promotes students' eco-friendly behaviour effectively if they get to actively participate in problem-solving and the project has clear objectives. Also social support and feedback are important. Social approval, rewards and punishments are potential sources of external motivation, however, repeated use of these methods can hinder the development of inner control and thus getting long term results.

Opening up with drama activities

Drama is a teaching method that brings out emotions and that can be used in chemistry education too! Here are some concrete ideas for chemistry classes.

Life cycle of a product: In small groups, the students compose a (silent) play based on life cycle posters* made earlier or some other pictures given by the teacher. Then, they have about fifteen minutes to rehearse a play that tells a story about a product's journey from cradle to grave, or alternatively, about recycling.

Values scale: First, a neutral interviewer asks the students a question about a certain issue and their values related to it with the help of a values scale. The students then move on the yes/no -scale based on their own answers. After everybody has taken their position, the interviewer randomly asks some of the students that stand on different places on the scale to elaborate on their views. Here are some example statements: we have to save energy all the time, we protect the nature, climate change is under control, I don't have influence over my own exposure to chemicals, chemical substances are always useful, I don't need to save water.

*see "The life cycles of our favourite products", p. 18

Inner circle: The students stand in a circle, facing out. One of them turns around, now facing the center, and tells something he or she is going to do to promote circular economy, or to save the world. Everyone who is willing to do the same thing also turns around, facing the center. The teacher can ask those who turned around if they have already put their plan into action. After the discussion, everybody turns so that they are facing outwards again, and it's someone else's turn to present his or her idea for saving the world.
Variation: the students throw a beanbag to each other in a circle and everyone has to tell at least one way of influencing environmental matters or a wish for the future development.

What can we do?: The students are given a floor plan of the school. In small groups, they go to different places, such as the copy room, school cafeteria, toilet or teachers' room. Each group has their own area of responsibility (such as pollutants, recycling, personal choices, energy or safety) that determines their point of view when it comes to saving the world. Based on their observations and results, they can, for instance, draw signs, write a letter to the adults in school or write an opinion piece to the local newspaper. It is important that the students get to put their ideas into practise. Another idea is to set up school's own "working party on environment". For more information, see: Care, Affect, Enjoy, Flourish sustainable development guide* or WWF's Sustainable schools guide. Both of these guides include a survey of the initial situations related to various themes.

Sustainable use of forests (discussion game): How can the conflicting needs concerning the use of forests be resolved? The PlayDecide game (in English) can be printed free of charge here: https://www.tiedekeskus-pilke.fi/fi/tule-oppimaan/playdecide/ OR on: www.playdecide.eu > play > download, on which there is a wide selection of games to choose from. The results of the game can be uploaded to the website.

Composing a play using the life cycle posters

*http://www.4v.fi/4v/in_english

The life cycles of our favourite products

The need for green chemistry and life cycle analysis is increasing because the resources in the crust of the Earth are running out. Also, the increase of chemicals in our environment makes life cycle analysis more and more necessary.

This project, developed and tested by chemistry teachers, takes approximately 5-10 lessons, depending on the amount of work done at home or in cooperation with other school subjects. With the help of the project, the students learn how to evaluate environmental burden of a product, in other words the energy and materials used in the production process (quality, amount, impact), and ways to find better solutions.

The fact that it is possible to study life cycle analysis at the university level shows the degree of complexity of the analysis. However, the students are not expected to reach this standard, but to work at their own level. So no stress! In this inquiry-based learning activity, the students analyse the life cycle of a product that they find interesting. Pictures of different production processes can be found on: www.madehow.com

When doing the life cycle analyses, the students look at the phenomena from the perspectives of different interest groups. They reflect on their thoughts and work in small groups. They learn how to assess their peers, present arguments and make decisions. The students put together a poster or presentation of what they have learned about the life cycle of the chosen product and present it to other students, or even to their parents and representatives of the city council. These presentations are meant to illustrate how far-reaching and similar the life cycles of different products are. This approach equips the students to take an active role in the society. After the project, the basic concepts of life cycle analysis can be applied to every product that is dealt with in chemistry class.

Students should be encouraged to practice decision-making and presenting their own opinions on the conflicts of interest concerning environmental issues. Therefore, it is advisable to focus on methods such as summary discussions, debates and acting as an opponent. The teachers have also included drama, field trips, learning diaries and debates as part

Different stages of the life cycle project

1. Introduction to the topic,
Using e.g. a video or guided discussion
2. The students
… come up with questions about life cycle thinking in small groups.
… choose a product that their small group finds interesting as their research subject.
… form their research questions.
… retrieve information from sources they find inspiring.
… gather their results using a medium of their choice.
… act as opponents of another group's work.
… improve their own project based on the suggestions they've received
… prepare to present the life cycle of their product and come up with two questions for their opponent group.
3. Presentations,
after which at least the opponent group asks two questions about the presentation.
4. Summary discussion and/or a debate related to the issues raised in projects, e.g. different ways to influence environmental matters and consumption.

of the project. When using these types of methods, the students should be aware of how their learning is assessed.

The concepts of MIPS (material input unit of service) as well as water, carbon and ecological footprint can be introduced when discussing life cycle analysis. The students can study how the food production crisis could be solved by using chemistry, considering alternative solutions in e.g. water consumption, recycling of plastic packagings or using fertilizer nitrogen. This leads to contemplation of ethical question concerning the use of water, fossil raw materials and soil in production processes. It has been noted that in chemistry, the students have the most difficulties in practical exercises related to raw materials and ethical contemplation. Questions* asked by the teacher or the students can be classified as follows:

Society

• What is the price of the product and why?
• How does the product affect the environment, economy and general well-being?
• How do I make responsible choices?

Technology

• How is the product manufactured?
• From where do we get the raw materials of the product?
• What happens to the product after being used?

Science and Chemistry

• What is the chemical composition of the product?
• What materials and resources are needed in order to manufacture and use the product?
• What types of emissions does it cause in manufacturing and after being used?

Environment

• What environmental problems are related to the manufacture of the product?

The objective of the life cycle analysis is to develop and rouse holistic thinking in students. At a simplified level, life cycle analysis enables the students to analyse economical, energy and resource policy -related aspects as well as national consumer habits as a part of global material flow. The analysis is a way to became aware of materialistic consumer habits and their impoverishing effect on nature and lives of millions of people.

Variation: Choose products that can be produced in a laboratory (e.g. lotion, soap, bouncy ball or paper, or other products that can be made at home or in woodwork or craft class from scratch, starting from the raw materials). In small groups, the students put together a poster (this can be done in cooperation with other subjects such as mother tongue and geography). When the posters are ready, the students can act as specialists and present their work to adults, for instance in library or in parents' evening.

***More example questions: Why are the particular materials chosen to manufacture a product? What natural resources have been used to get the materials? Have animal experiments been used in product development? Has the production and transportation of the product consumed a lot of energy? Where and how is the product used? Is it used a lot? Is the product truly necessary or absolutely useless? If the product breaks, is it easy to repair? Is the product or its parts recyclable? How? Can you think of ways to reuse the product or some parts of it?**

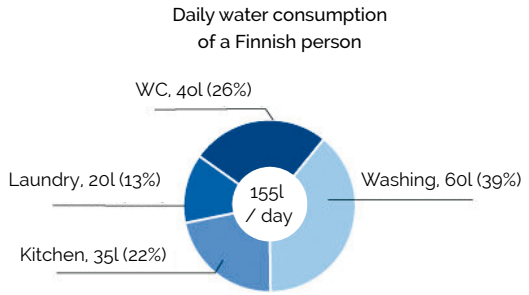
The number one thirst-quencher is drying up: water

Inquiries related to water include topics such as circulation of water in nature, water consumption and the journey of our drinking water from water intake facilities to tap, and back to nature through water treatment stations. The students can write separate reports on the experiments, or do a larger project and a research report.

Introduction to the topic: The teacher chooses a suitable video on water resources/circulation. After the video, the students can think about the following questions:
How are the water resources distributed on the Earth? What about water consumption?
How much water does an average person in my country consume?
What is meant by hidden water, chemicalization, microplastics and garbage patches in the oceans?
Do I need to save water?
With the help of the padlet -tool, which promotes communal learning, students' questions and answers can be gathered on the board in real time.

Water consumption: The students measure their own water consumption with the help of personal water footprint calculator*. At the same time, it is important to remind the students that domestic water use is only about 10% of the overall water consumption, and as much as 90% of water is consumed by industry and agriculture. The UN has published material on water justice, and the "Water facts and trends"* brochure includes illustrative tables and figures about the issue.

Distribution of water resources: This can be illustrated by freezing two decilitres of water (=glaciers), taking one decilitre of fresh water (=groundwater, reservoirs, lakes, rivers, water absorbed in soil and plants, vapor) and 9,7 litres of salt water. These proportions illustrate how water resources are distributed on the Earth. It can also be pointed out that 70% of the Earth's surface is covered with water, whereas only 30% is land.



*www.unwater.org/downloads/Water_facts_and_trends.pdf

www.waterfootprint.org / www.watercalculator.org

Water-related activities in English: http://www.thewaterschool.co.uk/teachers.html

Water themed field trip: Field trip destination can be e.g. local water intake facility, water treatment station, swimming hall, water tower or some water ecosystem. Before the trip, the students come up with questions that they can then ask on the spot. If possible, you can collect water samples from the place you're visiting, and later analyse them in a laboratory. After the trip, the students can make a scheme on household water treatment.

Analysing water samples: The students can measure, for example, water's pH, temperature, turbidity, electrical conductivity, oxygen content, oxygen consumption, hardness or iron content.
You can find instructions on: www.seametrics.com/water-lesson-plans

Solar Still

Man-made ground water: Cut off the bottom of a plastic bottle. Then, build filters in the bottle using different materials such as gravel, sand, vegetable fibre and activated carbon, and pour some dirty, untreated water in the bottle. Put filter paper or fabric in the place of the cork and use an elastic band to secure it. You can then place the bottle in a clamp, put a beaker under it and let the untreated water drip through the filters. The students can then ponder on whether the water is now drinkable, discuss on groundwater recharge and the reasons for it. For more information on ways to chemically purify surface or man-made ground water, use the entry "water disinfection". By doing a search using entries such as "water treatment camping" you'll find commercial water filters and purifiers that you can compare to your self-made ones. For precipitation of muddy water, add a few drops of aluminium sulfate or ferrous sulfate.

Man-made ground water

Solar distillation of water: The students build a distilling apparatus that works on solar energy*. You'll need a glass dish with salty water that is coloured with food dye. Cover the dish tightly with cling film and place a small weight on top of it,

*For pictures and instructions, search for "solar stills".

right in the middle. The heat of the sun makes the water to evaporate, after which it condenses on the cling film and drops to a smaller dish, placed in the middle of the larger bowl. After the experiment, the students can analyse the quality of the distilled water, as well as measure its amount and percentage in relation to the total amount of water. The experiment also brings up good discussion points, such as water purification and different states of water.

Distillation challenge: The students design and build a solar distillery that is as effective as possible, criteria can be e.g. distillation speed or percentage. The students can come up with the variables (such as time, temperature, shape and colour of the dish and the amount of water) and record them by drawing, writing or photographing. As homework, they can do a new experiment by changing these variables. This activity can also be integrated with mathematics.

Microbiological studies on purity of water (to be integrated with biology): Producing nutrient medium for petri dish, dissemination of water samples, growing and counting of colonies.

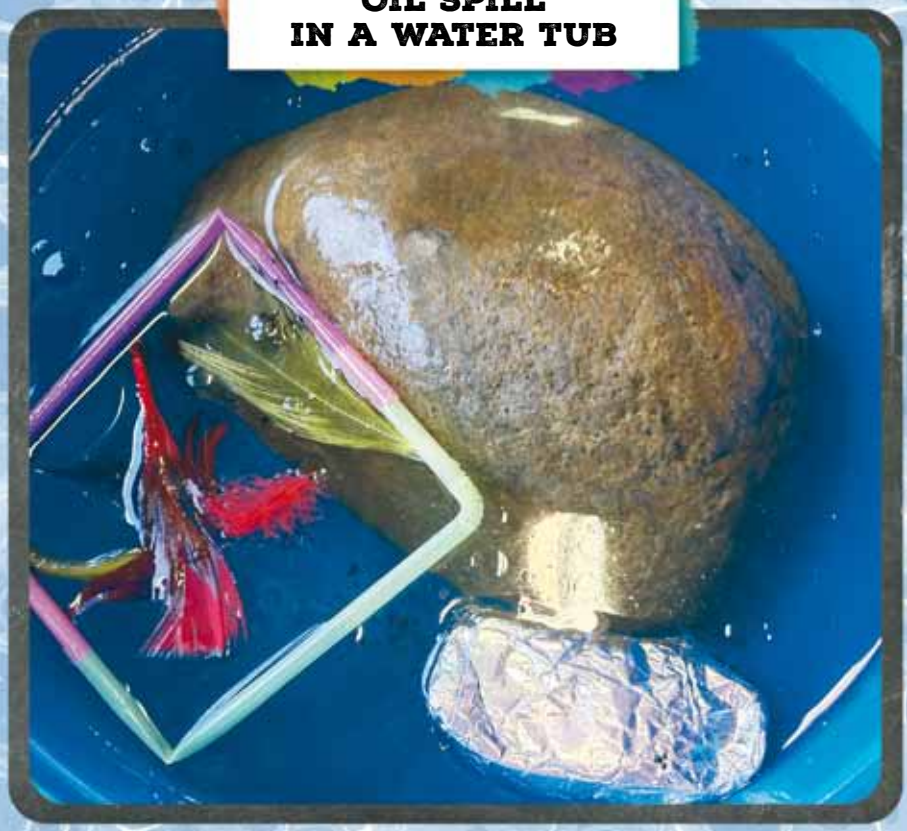
Using duckweed in the lab: Duckweed can be grown in a dish. To get more instructions, search for: "education Lemna minor".

Water tasting (to be integrated with geography): Some of the students act as organizers of the tasting and others as experts. You'll need different types of mineral and spring waters, tap water and some glasses.The tap water should be put in a separate (unscented) bottle and placed in the fridge with other water bottles so that all the waters are of the same temperature. First, the tasters taste different waters without knowing which is which. Then, they give them scores and list them in order from best to worst, taking into account the colour, smell and taste of the water samples. The results are recorded on the board or a separate form. Finally, the tasters are told which waters they have just tasted. Was there any disagreement between the tasters? What could cause the differences in taste? Is it sensible to buy bottles of spring water from a store? What do you think about importation of water from other countries? What environmental effects do different ways of producing drinking water have?

Acidification of water: This experiment simulates the acidification occurring in the oceans*, in other words how carbon dioxide is water-soluble acid gas. First, put a few drops of BTB indicator into a beaker that has water in it. Then, blow air into the water with the help of a straw for a few minutes. This causes a change in acidity of the water and the BTB changes its colour from blue to green. You can also study how acidity (e.g. cola) affects egg shells, bones or marble.

*** The biological pump of carbon dioxide is an interesting research topic. The connection between the phenomenon and ocean acidification is not yet fully known, but the amount of CO_2 in the air is directly proportional to the amount of CO_2 dissolved in water systems. On the other hand, the dissolution and release of CO_2 is a dynamic reversible reaction: dissolution increases when the temperature decreases, and decreases when the temperature increases. Therefore, it is possible that in the case of temperature increase, the oceans become sources of carbon dioxide emissions, instead of carbon sinks. To get illustrative pictures, use entries:" ocean acidification chemistry climate change".**
Check also videos about ocean chemistry and coral bleahing phenomenon from Youtube channel called RootEd.

OIL SPILL IN A WATER TUB



Oil spill: The students learn about this environmental disaster by simulating an oil spill. The water tab represents the ocean and the students make their own oil tankers using foil. The tankers run into the rocks and feathers (=birds) in the tab, and the oil (cooking oil coloured black with coal) spills into the water. The students try to prevent the oil from spreading by using oil booms (drinking straws), trying to soak up the oil with the help of sawdust and lime, and adding a drop of detergent to the oil in order to disperse the oil slick and increase evaporation. Does the oil dissolve in water? Is it easy to clean up the spill? What happens to the birds? What is the best way to prevent future oil spills? How does the spill affect the environment?

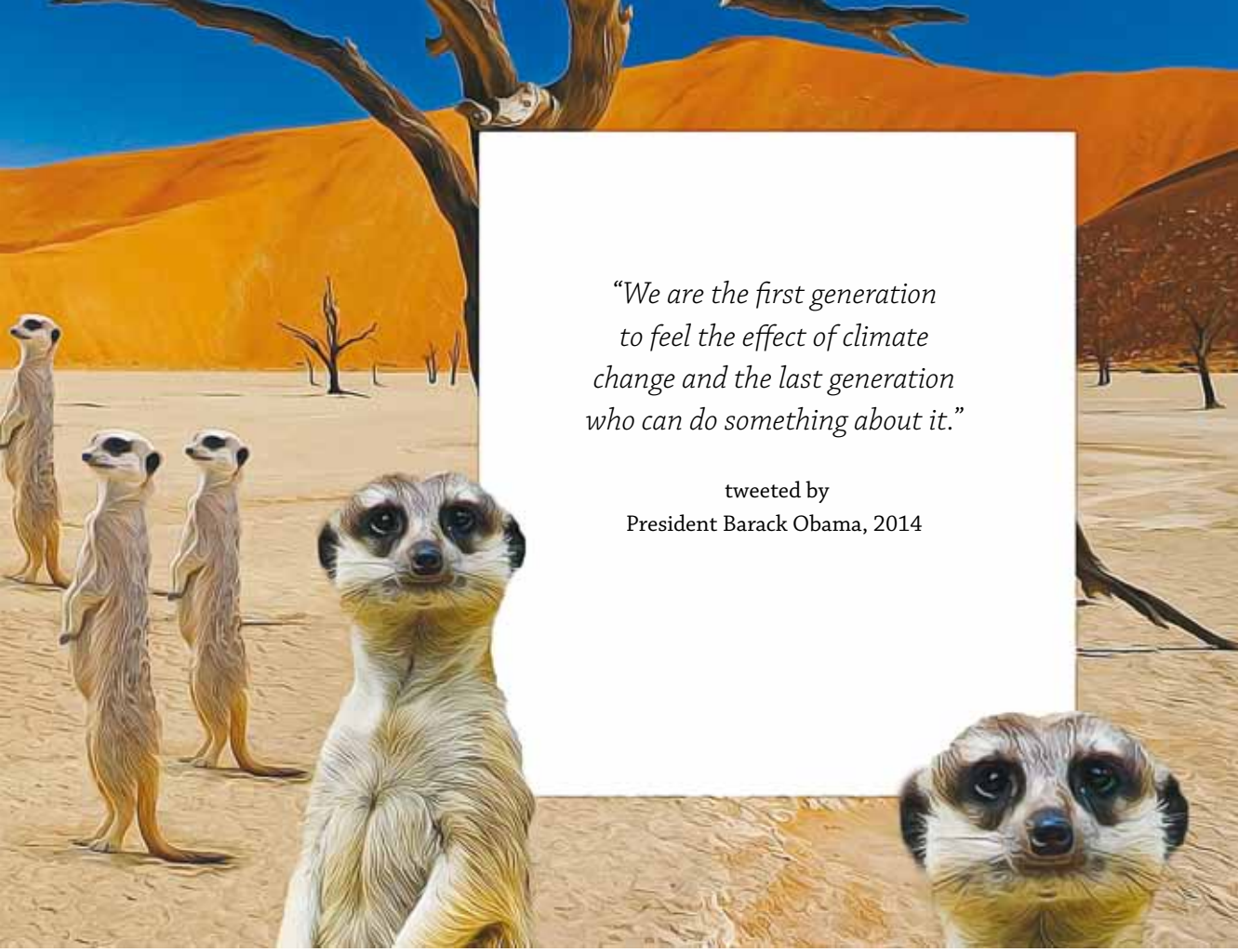
Let's stop the climate change together!

Introductory questions and activities: What chemical substances cause the phenomenon and why? What type of molecules are they? In what kind of reactions are they generated? What is the carbon cycle? You can also go over the concept of carbon footprint and the chemistry related to it (e.g. CO_2, CH_4, N_2O, O_3, water vapor, halogenated hydrocarbons,carbon dioxide equivalent). You'll find more information by searching for "greenhouse gas". Also, there are plenty of videos about the greenhouse effect on Youtube. How big is your carbon footprint? In Finland, the average of annual carbon dioxide emission per person is about 8500–9000 kg. It should be reduced to 5500 kg within the next ten years in order to meet the global climate targets.

My carbon footprint and how to reduce it: The students measure the average carbon footprint of their family. They find out the information needed for the calculation (e.g. the annual energy consumption of their house) as their homework or alternatively the teacher helps them with the variables. You'll find carbon footprint calculators here: www.footprintnetwork.org > footprint basics > personal footprint.

The students can compare their results and think about the variables that have the biggest effect on their own carbon footprint. The three main categories of carbon footprint are travelling, living and eating. In this connection, the effects of climate change on welfare and future can also be brought up.

Check also:www.syke.fi/en-US/Research_Development/Sustainability_of_consumption_and_production/Calculators



International climate panel (role debate): The roles are: USA (strongly dependent on oil), EU (speaks up for emission reductions), Finland (has industry that requires energy), Greenpeace (environmental organization that stands for renewable energy and saving energy), India (newly industrialized economy, whose development is constrained by emission regulations), Ethiopia (poor developing country suffering from drought because of the climate change), the Maldives (island nation that is in danger of sinking because of the rise in sea levels, but that is also dependent on air traffic) and Saudi-Arabia or alternatively Russia (oil producer countries).

Climate diet (homework): The students (and the teacher!) plan a climate diet for themselves or for their families. With the help of the diet, they reduce their annual carbon footprint by 10% per year, over a period of three years or until the goal is reached. Here are some example questions for the sum-up discussion:
What is your life going to look like in three years? What choices have the students decided to make? Is there anything that makes it difficult to make these choices (e.g. consumerism, comfort-loving, social structures, economy)? How does our excessive way of life affect the people in less developed countries? What about next generations? What kind of technologies can be useful in preventing climate change? It is also good to bring up the limited role of technology in solving the climate problem.

(teaching ideas by Sakari Tolppanen, Ph.D.)

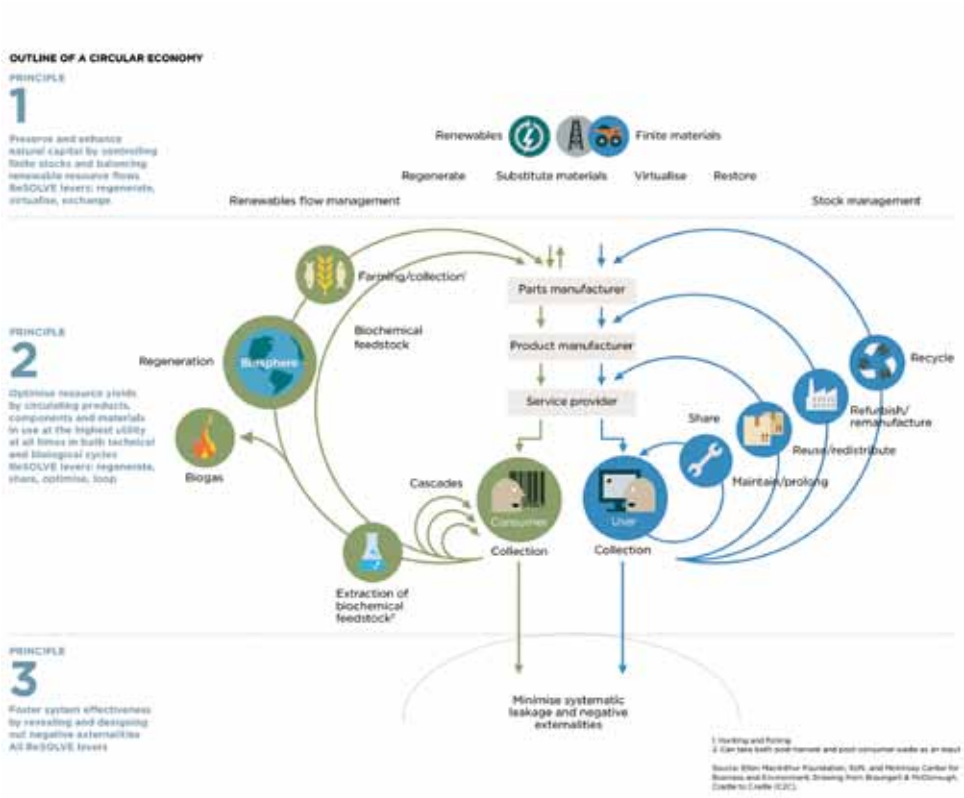
Circular economy changes the society

Circular economy is an economic model that promotes sustainable use of resources. According to some estimates, by 2030 the people on Earth will need 50% more food, 45% more energy and 30% more water. (Source: Finnish strategy for bioeconomics, TEM, 2014).

Introductory questions: When was the last time you recycled? In what way? Why do we recycle? What are the ten most important products that you own? Why do you need them? After the discussion, the concepts of circular and biobased economy are introduced.

Circular economy (cooperative learning, teaching idea by Jeskanen, 2015): In groups of 5–6, the students study a new topic (e.g. proteins, polymers, fats, renewable energy and other energy sources). After that, these home groups get a list of topics related to circular economy and each student chooses one topic* that he or she finds interesting. All the groups are given the same list:

- Biofuel from tall oil
- Cancer medicine from spruce
- Timber as a building material
- Wood pellets as an energy source
- Woodcast



Source: Ellen MacArthur Foundation CE Team

• Biocomposite from cellulose
• Textile fibres from wood fibre
• Biofuels from waste
• Improving separation processes to get cleaner fractions and the use of these fractions.

Based on their choices, new groups are formed. These groups then design a study and specify their research questions. While doing the study, each group member should bring out how the topic of their homegroup relates to the research subject. The teacher can also invite a guest speaker than can answer to students' questions. Then, the research group gathers their results to a medium that inspires them, such as online blog or a video. The teacher encourages and helps the students at every stage of the research. The research groups present their studies to other groups, who give them feedback and proposals for improvement. Finally, the students go back to their home groups and share the new information that they have learned concerning their home group's topic. The students can also come up with different exam questions, that are then shared with everyone.

Eco-homes (integrated with drawing and physics): In groups of 4–6, the students build an eco-home in a big carton box. Students' own ideas and discussions are in a key position. The teacher gives some instructions, but lets the students decide what they want to build in their eco-house:

compost, kitchen garden, wood, heat storing fireplace, solar panels, windmill, biogas reactor, compost toilet, thick walls, building materials, windows, changeable walls, natural light, LED lights, green roof, well, solar thermal collector heating the water, utilization of greywater, eco-friendly detergents etc. The project can be extended by writing short bulletins about different parts of the house, or organizing "an eco-house exhibition" in the library or some other public place.

***Examples of relevant topics in 2016 (Finnish innovations): BioVerno (renewable biodiesel), HMR lignan (studied because of its cancer preventing qualities), wood pellets (e.g. Versowood's HOTTI -pellets), Woodcast (developed by Onbone Oy), UPM ForMi (a new cellulose fibre reinforced plastic composite) and Ioncell (a new type of textile fibre made of wood fibre) or dissolving pulp (fabric).**

Eco-efficient and healthy snacks

When using animal products, such as eggs or milk, in chemistry class, it is important to take a moment and consider the ethical issues that are related to food. It should also be emphasized that the experiments are not about playing with food, but a part of scientific research. Unfortunately, the food is no longer edible after the experiment, but it can still be composted.

As much as a quarter of the climate effect resulting from domestic consumption comes from food. If we also take other environmental effects, such as eutrophication, acidification and changes in diversity, into consideration, and add that to the carbon footprint, we can conclude that one third of the pollution load results from food, which makes it an even bigger polluter than living and transportation. Producing animal products usually requires more resources and energy than the production of vegetable food. Animal products play a significant role in many of the environmental crises.

Favoring seasonal vegetables and minimizing the use of animal products are key factors in sustainable diet. On average, even the imported vegetable food is surprisingly climate friendly because of the efficiency of current containerization techniques. Another easy way to promote sustainable diet is to pay attention to the amount of food waste. A piece of bread or ham that goes to waste burdens the environment more than the life cycle of its packaging. Therefore, the most eco-friendly packagings are those that generate the smallest quantity of food waste, and that are made of recyclable materials. For more information, search for "climate friendly food".

Introductory questions: Why do we attempt to minimize the amount of substances we use in chemistry class and in kitchen? Why do we buy organic food? How are the ingredients produced? What resources are required in order to get this meal on my plate?

Comparing protein sources (integrated with domestic science): The students place different food supplies (e.g. cheese, fish balls, chicken, cold cuts, lentils, peanut butter, tahini, tofu, beans, nuts etc.) in order according to their protein content. The protein contents can be found on the label of the package or on www.fineli.fi (also in English). In this connection, it is also important to talk about the amino acid compositions of different food supplies. This activity introduces the students to many new protein sources. The students can calculate the amount of each food that is needed to satisfy their daily protein requirement (about 1–1,5 g/weight in kg). In addition to their environmental effects, it is important to talk about the nutritional quality of amino acids: we need to have different protein sources to make sure we get all the amino acids we need. After this, the students can compare other nutrients and their qualities in the same manner.

Building a compost and kitchen garden: The students study the nutrient cycle in a concrete way. The most important plant nutrients in fertilizers are nitrogen, phosphorus and potassium (NPK fertilizer). The manufacturing of these substances is based on fossil processes. The big crops of the modern industrial agriculture are dependent on these fertilizers. To see how fertilisers are manufactured, visit www.madehow.com/Volume-3/Fertilizer.html or search for "production of fertilizers" and watch an illustrative Youtube video. The phosphate in phosphorus fertilizer and the potassium chloride in potassium fertilizer mainly come from mines. It has

Tip! Check out interesting educational videos from Youtube channel called RootEd. They are related to e.g. food, soil and energy issues.

been estimated that the global mineral phosphorus reserves are depleted in the next 50–100 years. Nitrogen fertilizers are made of ammonia that is taken from natural gas. You can find chemical equations with the entry "Haber Bosch process". Fertilizer production requires a lot of energy and therefore new innovations are needed. For instance, the sludge that comes from manure pits and compost toilets, as well as nutrients from bio waste, should be recycled, but as of yet, there is no profitable method for doing that.

Analysis of different kinds of soils: The students compare different types of soil. Why can't you grow vegetables in a soil that is produced for flower cultivation? What is the composition of the soil in a compost or in a kitchen garden? The students can collect samples from the ground and do a soil fertility assessments. Also, many companies do these assessments with ten euros. For more information, search for "soil fertility assessment".

***When using material provided by a company, bring out the issue of independent information; contradictory or delicate issues are rarely brought up by the company's communications.**

To mine or not to mine?

The limited nature of ore bodies in the Earth's crust is a significant factor when new materials or technologies are developed in chemical industry. Nowadays even mineral sites with low concentrations can be quite effectively exploited, but at the same time, worries about the environmental effects of mining arise.

In chemistry education, it is important to take the whole life cycle of a metal or mineral product into consideration, so that the students learn about mining processes and understand the original source of a consumer product. Metal recycling is an efficient way to save energy and natural resources.

Life cycles can be looked from the perspective of new innovations. You'll find many interesting articles about, for example, new battery technology and electric cars by using entries "battery innovation". Another perspective could be the limited ore reserves and environmental problems related to mining industry. For more information on the problems related to metals used in electronics, you can watch a video called Story of electronics*: storyofstuff.org/movies/story-of-electronics/.

When it comes to the concept of circular economy, it is also noteworthy that the lead in car batteries can be recycled and used in the process of making new batteries. Similarly, the plastic parts of the old batteries can be used as material for new ones. The acid is neutralized, which makes it safer to handle. You'll find videos about these techniques on Youtube by searching for "Lead battery recycling" or "recycling batteries" (a silent animation about recycling of alkaline batteries).

Mining industry - role debate: The roles are: local chief of a global mining industry (lobbies and advocates on the behalf of mining industry), a member of a city council in a small, uninhabited village (wants to create more jobs in the area), a sheep farmer (is worried about his pastures and water purity), a member of an environmental organization (is worried about emissions and the loss of valuable ecosystems and ecosystem services), chemist consultant (is familiar with mining processes and emissions caused by them, has been hired to evaluate the environmental effects by the mining company), licensing authority (stays neutral, but requires the mining company to make a legal license application, and that the opposing arguments are presented in a form of a written reply), an owner of a summer house (doesn't want a mine near to his/her summer house) and land owner (wants to sell his/her land to the mining company).

***For more information, use entries "rare earth elements". Note that the sustainability reports made by the mining industry itself should be viewed critically.**
A tip! Lesson plans related to e-waste (suitable for all ages) can be found on www.ewaste-education.org/. For teaching ideas about batteries, search for "green batteries lesson plan".

New products and recycling

Recycling is possibly the easiest and most common first step in protecting the environment. It is probably the most familiar topic of sustainable development to the students, because it is usually brought up at an early stage of education and discussed in many different contexts.

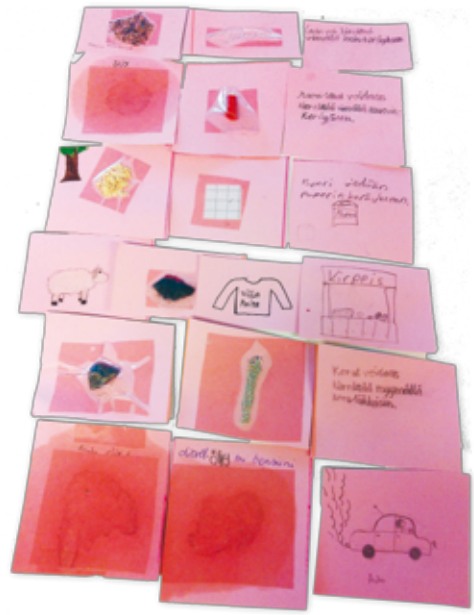
The teaching of material chemistry should be linked with the concept of circular economy. It is necessary to learn how to utilize different materials efficiently, for example as raw material (remelting of glass and metal), as new products (making school hand towels out of old bed sheets) or by recycling them directly (bottle banks). The last alternatives are to either burn the material to produce energy or bury it in a landfill site.

Introductory activities: You can show the students a Youtube video called "Life of a plastic bag". After watching it, the students can think of how to prolong the lifespan of a product (e.g. a plastic bag, text book, chair, or jeans).

Recycling field trip: You can make a field trip to, for example, the storage of a local store, recycling center, waste management centre or other recycling-related company.

Recycling survey: What does your family recycle? As their homework, the students make a list of all the products that their family recycles. They can also interview their family members: Why do (or don't) you recycle? Could there be more products to recycle? Working with their partner, the students choose one recyclable product and find out its recycling process and ways it can be reused.

An idea for elementary school: The teacher brings pieces of different materials to the classroom, and the students glue them on a paperboard, dividing them into three categories: raw materials, products and recycling. This way they illustrate the life cycle of a product, such as a sweater made of sheep's wool that is then recycled by felting or burning. Finally the paperboard can be cut into cards and the students can play a game in which the player has to find groups of three.



Nanopinion (discussion game): This debate related to nanotechnology is suitable for both secondary and upper secondary school students. The lines and statements are given to the participants. The game can be found on www.scientix.eu > resources (choose type: Role play, and language: English > Go! > Get this resource)
More teaching ideas in English can be found on nanopion.eu > Education

Debate on plastic: This debate is suitable for upper secondary school students. There are different roles (regulators, health, industry, invention, sustainability, waste) that all have different goals. The game can be downloaded on www.chemheritage.org/conflictsinchemistry , and the goals for different roles can be found at "Goals and recommendations".

Observing different materials around us: Working in pairs, the students walk around the school and make observations on different materials used in the building, furniture and products (exterior and interior walls, roof, ceiling, floor, doors, windows, furniture, furnishings and other objects). They make a list of the materials they have found (stone, metal, glass, brick, concrete, wood, paper, paperboard, plastic, composite, textiles, gypsum, foodstuff or cosmetics).Then, they mark down where each material was used and write down the most important properties of different materials when it comes to products. Then, they can discuss why different types of materials are needed and think about their subtypes, origin and alternative ways of using them.

Variation: Each group gets one material. After the activity, the groups share their findings and the students gather all of the information by gluing pictures on one big poster. This giant poster is later presented to other classes or the parents.

THE STORIES OF TWO WATER BOTTLES

Storytelling is an emotionally engaging teaching method that helps the students remember what they have learned. What feelings do these two stories provoke in you?

Loser Bottle

The bottle is brought to a local store on a pallet. The bottle is placed out in a refrigerator case. A tourist from another continent buys the water bottle. The tourist is thirsty and drinks almost all of the water. The tourist spends the day sightseeing and finally notices that the rest of the water is now warm and the bottle smells like plastic, so the tourist just leaves it on the ground.

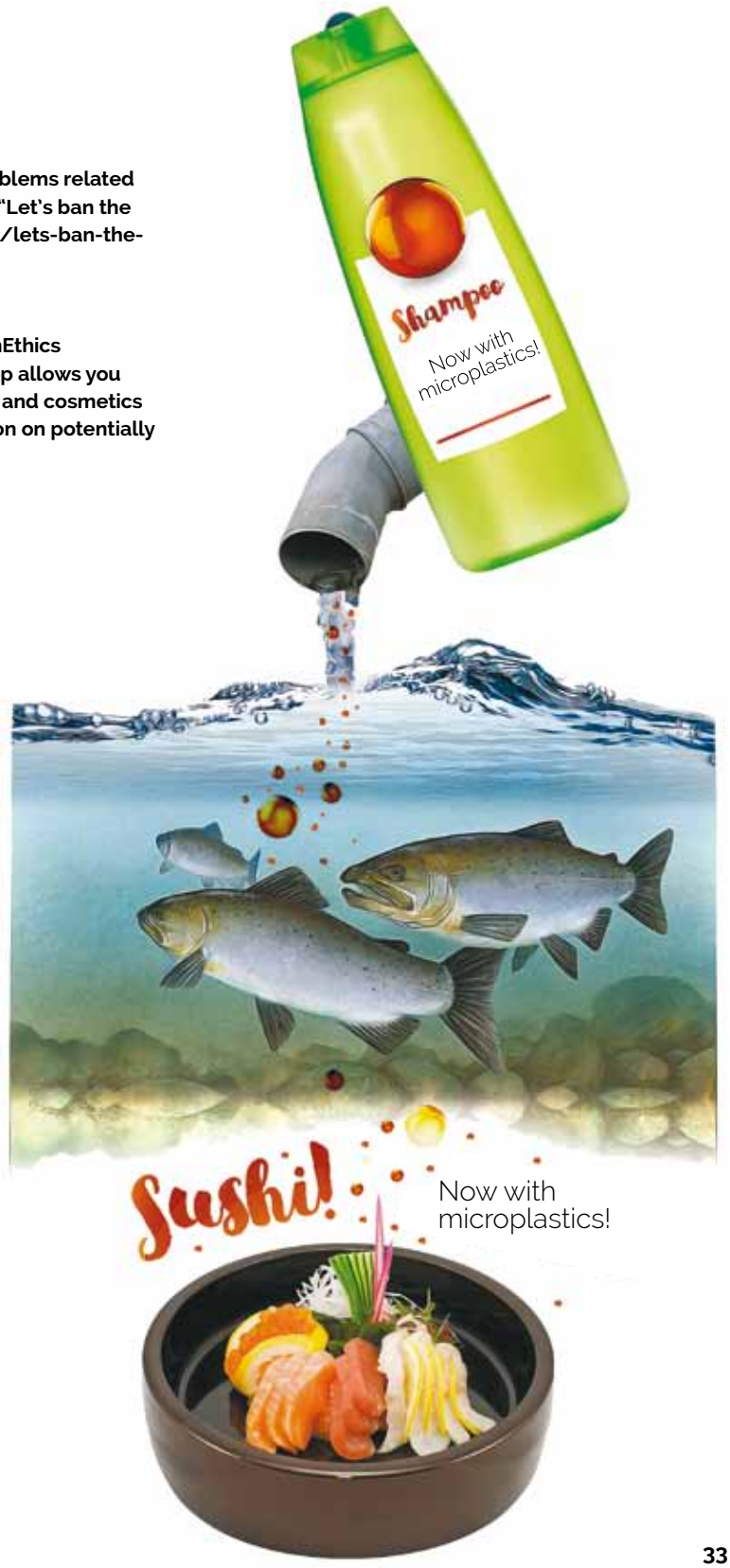
The wind drives the almost empty bottle to the nearby river. The river carries the half-sunken bottle to the Baltic Sea. Gradually, the bottle turns into microplastics. Some of it ends up eaten by fish, which then become sick due to the chemical additives in the material of the plastic bottle. Some of the microplastics end up as a part of a big garbage patch in the middle of the ocean. Finally, the sick fish ends up on your plate and because the microplastics or harmful chemicals can't been seen with the naked eye, they end up in your stomach.

Winner Bottke

The bottle is exported to another continent in a big steel container. In the harbour, the containers are unloaded and left for further transportation. Then, the container is loaded on a smaller ship on the way to your country. The ship arrives in the harbour of the capital, and the container is transported to a central warehouse in which the boxes are shelved. A store in your city orders one box of water bottles. One platform full of boxes is transported by a truck to an intermediate storage. From there, a box full of bottles is loaded on a truck and transported to a warehouse in a city nearby. From there, the bottle is transported to a store in your city, from which a hiker buys it. The hiker stops at a market place and drinks the bottle of water he/she has first cooled in a mountain brook. The hiker is about to throw the bottle in a fire, but then realizes that it can be used as a water bottle because the water in the brook is drinkable. After the hike, the hiker returns the bottle to a bottle bank.

A tip! For more information on problems related to microplastics, watch the video "Let's ban the bead" on storyofstuff.org/movies/lets-ban-the-bead/

A tip! You can download the CosmEthics application on your phone. The app allows you to scan the bar codes of toiletries and cosmetics products and gives you information on potentially harmful ingredients.

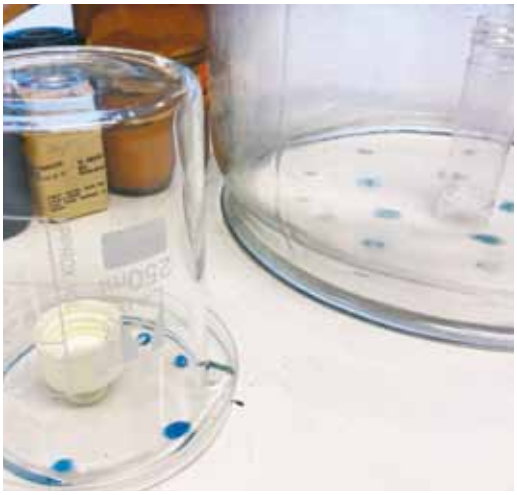


Product design in a laboratory

A tip! To find experiments related to sustainable development, use entries "green chemistry experiments for students".

Green factory: The students study how sulphur dioxide caused by industry affects the environment and how to prevent emission fallouts by neutralizing gases. Sodium sulfite and 2M hydrochloric acid cause the reaction, which mimics a factory. The acidic gases (SO2) of the reaction fall on colour-changing plants (BTS-indicator droplets) around the industry. The gases can also be neutralized in the factory by using calcium oxide filter on the pipe. This reaction produces gypsum. Students can investigate how to reduce or prevent the fallout, and how the length of the pipe affects the fallout. A test tube can be used as a long pipe and a cap as a short pipe. Use blue-tack to attach the pipe to the centre of the petri dish. Also real leaves can be studied.

Green factory



Lotion manufacture: Extract herbs or flowers at the temperature of 50 degrees for 24 hours in order to extract oil. Alternatively, you can also use extra virgin almond or coconut oil. Then, take 110g of cooled oil and mix it with 20g of beeswax (cosmetic grade) in a hot water bath. More information on the ingredients can be found on http://www.making-cosmetics.com/. Note that the website doesn't bring up issues related to sustainable development or chemicalization.

The teacher can also combine other activities with the manufacture of lotion, such as portfolio, making perfumes using learning stations teaching method (by e.g. dissolving orange peel in alcohol), sniffing and making of different types of soaps, drawing and building structural formulas, comparing synthetic and natural soaps based on their INCI lists, discussing the significance of emulsifying agents (e.g. by mixing acetum, oil and water), watching a video about how soap works (there are

***For more information, search for "synthetic musk fragrances" and for learning stations teaching method, see Marks & Eilks, 2010, Chem. Ed. Res. Pract. 11.**

several on YouTube), writing an article or having a debate (roles can be e.g. experts on consumer safety, water treatment, production and environmental protection). Synthetic musk perfumes include ingredients that affect the hormone action and could potentially cause cancer.

A tip! Watch a video: http://storyofstuff.org/movies/story-of-cosmetics/

Hair spray experiment: The students spray hair spray to a glass plate and see how a plastic-like surface emerges on it. They read the list of ingredients in the hair spray. In addition to plastic polymers, hair spray includes alcohol, perfumes and propellant gases. This is a great real-life example of organic compounds and an opportunity to discuss different perspectives concerning the benefits, environment and health.

Nickel test: Pharmacies sell dimethylglyoxime (DMG) spot tests for nickel. Rub an object using a cotton stick with a drop of DMG solution. If the product contains a harmful amount of nickel, the cotton bud turns red.

Natural dyeing: Different plants can be used to dye wool, silk, linen, cotton, paper, wood and leather. To get the colour fixed, the fibre must be treated with mordants, such as oxalic acid in rhubarb, formic acid in nettle, ash lye, acetum, citric acid, table and sea salt, iron and copper sulfate and alum. For more information, search for "natural dyeing", and for more detailed instructions, visit Sweet waste dyes blog: suloisiavareja.wordpress.com

Paper production: Shred waste paper into pieces and soak it in water for few hours. Instead of waste paper, you can also use straw, cotton grass, birch leaves or nettles, but they have to be softened first by boiling them in soda water. Mix the soaked paper fibre and water with the help of a blender so that the consistency becomes porridge-like. The strength of the pulp can be increased by adding paste or starch while the mixture is boiling. The appearance of the pulp can be enhanced by adding spices (e.g. cinnamon, chili, pepper or curcuma), or by using water colours or coloured paper. Use wire to separate a portion from the pulp and strain off the extra water. Place it on a felt and press it with a sponge in order to get the extra water out. Be careful when pulling the wire out. You can enlarge the paper by adding more pulp next to it. Dry up both the felt and the paper on a clothes line. For more information, search for "handmade paper".

A tip! You can find tons of ideas for chemical experiments on: www.nuffieldfoundation.org/teachers >chemistry

Going into the wild!

Students' nature connectedness and environmental literacy can be supported by moving the classroom outdoors, also in chemistry education. The students can ask their own questions about, for example, nearby water systems or soil, and in this way the new information is constructed together, while connecting it to an emotive experience.

Here are chemistry teachers' ideas for teaching chemistry outdoors:

- Collecting samples from the soil, water and air and analyzing* them (e.g. Visocolor school -reagent case includes simple water analysis kit)
- pH tests
- Naturally occurring pH indicators (e.g. blueberry)
- Picking flowers for natural dyeing
- Observing different rock types
- Purification of grey water
- Drawing structural formulas with a chalk on blacktop

Solar cooking: A summer activity in which the purpose is to heat up food or water in a carton box lined with foil. For pictures and instructions, search for "solar cooking".

Many of the water-related activities (see pp. 20-23) can also be done outdoors.

Being a friend to yourself and to others

Social sustainability is one of the dimensions in sustainable development, and it means, amongst other things, promoting health and spirit of solidarity. Here are some ideas for promoting social welfare in chemistry education:

A promise tree: The students make a tree of sustainable development, to which they stick promises of doing good deeds for both themselves and for others. These promises can also be related to chemistry!

Art with chemistry: The students make sugar rainbows to appreciate the beauty of nature or love in all its colours. Carefully, the students pipet sugar solutions of varied concentrations into a test tube. Then, the solutions are dyed with different food dyes, or natural dyes (e.g. beetroot, orange or flowers. For more information search for "natural dyes").

Dry distillation of tobacco: Instructions can be found by searching for "dry distillation of wood", just use cigarettes instead of wood. The gases generated during the heating are flammable. The residue concentrated on the sides of the test tube is comparable to the gunk in a smoker's lungs. Smoking is not worth it!

Mathematics as a tool for sustainable development

Circular economy mathematics: Recycling is the basis for circular economy, whereas sharing economy optimizes the utilization of goods. Have you ever wondered if the products you have bought are used effectively? According to Mari Pantsar, who works in the Finnish innovation fund SITRA, the average utilization rate of a car is about 5%, and of a office 40%. There are more than a million square metres of unused office space in Helsinki.

From the perspective of sharing economy, think about the utilization rate of your possessions. You can count the rate for your bicycle, home, classroom or any other item of your interest. Evaluate the information needed for calculation. Also, think how you could improve the utilization rate without increasing the actual usage.

Think about the unused office square metres in Helsinki. How long of a motorway could be built with those square meters? Or how high of a building? You can decide the breadth of the motorway or size of the building yourself, or search for information online.

What percentage of the commodities that you use can be recycled? If material has already been recycled once, can it be recycled again with the same effectivity?

Equations of sustainability: According to equation $I=P \cdot A \cdot T$, environmental impact (I) equals the product of three factors: population (P), affluence (A, i.e. how much people consume) and technology (T, i.e. the efficiency of technology).

Study the multiplication and think about its meaning. What happens if one factor grows and others decline? What if two of them grow and one declines? Or if they all grow? What if there is drastic changes and one of them, for example, becomes thousandfold or a thousandth. What if one of the factors is less than 1?

Apply the equation to your own life. Which factors affect the utilization rate or environmental effect of your commodities? You can use all the calculations that you think are necessary.

Sustainable development statistics: On http://www.oecdbetterlifeindex.org/ , there are interesting statistics concerning the environment. The students

try to find three different ways of displaying statistical data that they haven't seen before, which they then present to their partner. What type of data can be presented with the help of these types of figures? From the web page, the students choose five solid facts that they think everyone should know. Finally, they present their findings to others using a handmade poster or some digital platform.

On http://www.ssfindex.com/, the students can study a spider chart of the sustainability of their own country or other countries of their interest. They can then make their own spider charts of, for example, the sustainability of their class, family or hometown by evaluating or searching for the required information.

Examining microplastics: The students examine (cosmetics) mixture that contains microplastics. First, weigh one gram of mixture, let it dry and separate approximately one hundredth (ocular estimate). With the help of a microscope, count the number of micro granules in the sample and then using the result, calculate (approximately) how many micro granules the whole cosmetics product contains. A mixture containing micro granules is heterogenous, but if the number of micro granules in the product spread evenly in a 1000 litres of sea water, how many granules would be in one litre of water (granule density/cubic decimetre)? What would happen to the granules in sea water? How can the granules end up in your food? What does it mean when it comes to your health? What about the ecosystem? What products contain micro granules?

Mine mathematics: The Finnish mining company Talvivaara (founded in 2003) was supposed to become one of the biggest nickel mining businesses in the world. However, at some point it encountered some insuperable problems, the plans were frustrated and the mine polluted the local environment. In 2014, it went into liquidation.

The students can study the mine statistics related to their use of chemicals. According to one figure in Talvivaara Annual Report 2010 (p. 48), huge amounts of sulphuric acid were used in order to separate nickel. Sulphuric acid is neutralized with limestone, which causes a great amount of gypsum waste. The main problems were the storing of the gypsum waste and acidic waste water leaks.
The students can think about the amount of sulphuric acid. How many tank lorries are needed to transport 183600 tons a year? Or a day? Or in 30 years? With these amounts of chemicals, is it possible to use a close or open-loop recycling process? What do you know about sulphuric acid? Would

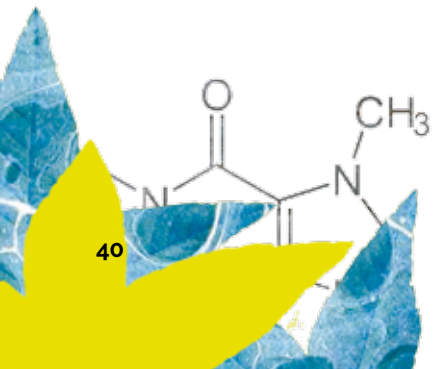
you like to have it, for example, in your backyard, or touch it with your hand?

The teacher helps the students to measure the pH value of sulphuric acid, which is extremely corrosive. The operational safety bulletin of sulphuric acid says that it is extremely corrosive to all body tissues and can cause serious eye damage. The damaging effect of sulphuric acid on aquatic life is based on its strong acidity. The pH value less than 5 is detrimental to fish, and value less than 5,5 is detrimental to other aquatic life. The acute LC50 value of sulphuric acid for fish is about 80 mg/l (24 h) and EC50 value for water flea is about 30 mg/l (24 h). The pH value of natural water is around 6,5. What does it meant that the pH scale is logarithmic? Why do living organisms perish due to small changes in pH? Also, find out what is meant by LC50 and EC50 values in animal testing.

My Ecological Backpack: Visit http://ressourcen-rechner.de/?lang=en and make a short test about your consumption. Is your consumption below average? How close are you to your ecological goals? Estimate the categories in the test by considering the amounts and numbers. Are there any things in which it would be quite easy to make big changes? What numbers are more difficult to reduce? In which categories in the test only small changes are possible? Is it possible to make small changes in several different categories and thus produce a significant change? You can also ask you parents or friends to take the test.

A tip! Find out what is meant by MIPS value. Try to estimate, calculate or find out MIPS value for a product you use.

Definitions, concepts and causal relations - modeling a system: The students attempt to model some interesting phenomenon, such as the climatic effect of air traffic, how bio waste decomposes, life cycle of a mobile phone ("from cradle to grave"), changes in polar bears' living environment or cultivation of organic kitchen garden. In small groups, the students list the processes and changes that occur in the system. Then they draw a figure in which they attempt to connect the different parts of the system together with arrows and curves, and by using colour coding and plus and minus signs to indicate the power relations between the different parts. There can also be two-way arrows to indicate reciprocal relations if this type of interplay exists. A lag in the interaction can be indicated by using



dashed lines. The students don't need to know "the right way" of modeling the system that they have chosen beforehand, but it is formed as they work together, constantly discussing and elaborating. Finally, the students present their group's end-result to their classmates.

If desired, the teacher can first make an example system together with the students, after which each small group works on their own project.

Diversity in Student Assessment

The principles for assessment should be introduced to the students before each project. The assessment should be based on mutually-agreed and curricular objectives.

Assessment can be focused on the ability to work independently and as part of a group, critical reflection and argumentation, consideration of different viewpoints and ethical issues, information retrieval, understanding the nature of science and the importance of chemistry. Depending on the task, the assessment can also be extended to taking action for the environment. Other learning goals, yet not as easy to assess, could be active participation and commitment to work for the benefit of the environment. With inquiry-based projects, the assessment can be focused on both active participation and laboratory reports.

A project related to life cycles can be assessed, for instance, by focusing on three different categories, from which a student can get 1-3 plus signs.

- Participation – active participation and hobbyism, giving feedback to others.
- End result – content, expertise (scientific expression in one's own words), argumentation
- Creativity – determining own research problems, versatility and clarity of the presentation.

In addition, the teacher can ask each group of students to formulate three test questions, from which the teacher chooses one from each group for the end of course exam. The groups can freely talk about the questions with other groups. This motivates the students to listen carefully when other groups present their projects.

When discussing topics that have conflicting social viewpoints, the continuous assessment (used by the teacher or students) can be simply marked as follows:

0 = a student doesn't have a chance to answer

x = a student doesn't influence the discussion significantly / decision-making and argumentation is unidimensional (e.g. based on easiness or cheap price) / Unscientific, inaccurate or unfounded information.

xx = a student participates in the discussion and finds at least two possible aspects (e.g. economic and scientific) related to the topic / Information is lacking, a student doesn't realize some aspects (e.g. social) without teacher's assistance.

xxx = A student takes a stand and skillfully reflects* on many aspects related to the topic / makes decisions based on economical, ecological and social viewpoints / Understands the conflict between the best alternative and current practices.

The learning goals in the new Finnish national core curriculum are so diverse that it imposes challenges on assessment. From teachers' perspective, student assessment should stay relatively simple so that the implementation of continuous assessment throughout the school year would be possible. Everything can't be assessed in every single lesson, but the students should be aware of the nature of the assessment. Assessment can be based on teacher's observations, discussions and questions presented by the teacher and students during the lessons, exams as well as self- and peer-evaluations. It is necessary to take notes on a regular basis. Also, it is important to remember that discussion about the grades works to the mutual benefit.

***If a student is forced to reflect under pressure caused by the authoritative role of the teacher, it may cause a relevant threat to genuine learning. Instead of forced reflection, teachers should focus on improving students' higher order thinking skills, learning skills and internal motivation.**

REFERENCES, LINKS AND CONTACT DETAILS

www.ecoschools.global
Graphics about sustainable development in Finland: findikaattori.fi/en and biodiversity.fi
Compare the situation in different countries: oecdbetterlifeindex.org and ssfindex.com
The State of the World - series of books by Worldwatch institute
Material for environmental education: wwf.panda.org/about_our_earth/teacher_resources/
A lot of ideas for education for sustainable development, example and survey forms and a calendar to support the sustainable development work: www.4v.fi/4v
Interactive web sites (different topics): http://interactivesites.weebly.com/science.html
Ecological foot print: http://www.angelo.edu/faculty/mdixon/ManEnvironment/Footprint-Web.swf

BIO- AND CIRCULAR ECONOMY
storyofstuff.org
Entries: Ellen Mac Arthur Foundation teaching resources
Youtube video: Environmental properties of materials, how to choose green materials
Youtube video: TEDx-talk: Chemical materials and sustainable design, Michael Werner

WATER
http://interactivesites.weebly.com/clouds--water-cycle.html
www.thewaterproject.org/resources/

CLIMATE CHANGE
http://climatekids.nasa.gov/

Juntunen, M. (2015). Holistic and inquiry-based education for sustainable development in chemistry. Dissertation. University of Helsinki.

Salonen, A. (2010). Sustainable development and its promotion in a welfare society in a global age. Dissertation. University of Helsinki.

Tolppanen, S. (2015). Creating a better world - questions, actions and expectations of international students on sustainable development and its education. Dissertation. University of Helsinki.

EXAMPLE TOPICS FOR ESSAYS AND POSTERS:

- The chemistry of chocolate
- Plastic pollution and micro plastics - solutions?
- The chemistry of mobile phones (What's in your phone? -Youtube video)
- Cultured meat and plant-based proteins: solution to the limited resources on the Earth?
- Bioenergy (entries: bioenergy, biofuel, biodiesel, bioethanol)
- Alternatives to animal testing
- Is it ok to pee in the ocean? (Youtube video)
- The chemistry of climate change
- Circular- and bioeconomy as solutions to the lack of resources
- Consumption, challenges and solutions of fresh water (entries: fresh water use, hidden water)
- How to avoid exposure to chemicals?
- Natural detergents and cosmetics
- Chemistry of food stuff that is conductive to health, such as ginger (entries: compound chemistry ginger) or antioxidants, vitamins, flavonoids

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