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special issue

"Science Education and Green Chemistry for a Sustainable Future"

*Based on a symposium that took place in the
AACE on the February 2016*

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Advocate Zaki Kamal; president

The Academic Arab College for Education in Israel – Haifa

Addressing the invited Authors

Scientific research is an essential standard for the development of human society as a whole. It is through scientific research that nations are perceived as developed countries that allow their populations to benefit from such a scientific accomplishment. We have witnessed how human progress and advancement transformed this globe into a more industrialized and technological place.

It is imperative to state that populations will not be able to progress without science and knowledge just as history teaches us. Namely, those who did not keep up with the pace of the scientific development got marginalized and weakened in this civil and human revolution.

Currently, we live in this small global village where interests, ambitions, and information exchange are interconnected and aligned. Large distances are not posing an obstacle anymore for those who seek knowledge and for exchanging information. It is through realizing these facts that we have become focused and devoted to our utmost resources at the Academic Arab College for Education for conducting scientific research and for holding scientific conferences at our academic institute. We believe that such activities will be a lever and a major pillar for exchanging information and experi-

ences and for strengthening academic relationships.

For the past 12 years we, at the Academic Arab College for Education, have consistently aspired to organize and hold equable international scientific symposia in order to stay abreast and keep up with the tremendous amount of generated information in our world. Through these activities, the college enables the faculty members to publish their research findings and attend international conferences.

Thus, it is not surprising, that this special issue of "Daruna" entitled "Green Chemistry and Teaching Sciences for Sustainability" is published by our college. This is done with the goal of strengthening the culture of keeping the environment safe; particularly since different types of pollution are reaching undesired and dangerous levels. Therefore, the need to deal with this issue is urgent as it negatively affects our social behavior, health, environment, and economy.

This special issue of "Daruna" was the result of our educational and academic effort as well as our interest to demonstrate our involvement in issues of global interest to humanity and to our environment in different places around the world.



Prof. Salman Ilaiyan

Head of the College

The Academic Arab College for Education in Israel – Haifa

Preface

The Academic Arab College for Education in Israel - Haifa is the oldest and largest Arab college in Israel. It serves the Arab sector since the establishment of the state with the goal of developing the Arab education in higher education system.

The college student enrolment is over 2,000 in the undergraduate and graduate levels including all disciplines taught in Arab schools in Israel - ranging from languages, early childhood and special education to science education in primary and post-primary levels.

The Department of Science Education in the college went through significant change in its infrastructure and laboratories, as well as the teaching and research faculty members in physics, chemistry, biology, computer science, and mathematics.

The science education staff has more than 35 faculty members with Ph.D. degree and post-doctorate research, working on developing learning materials and research, and their studies are published in local and international journals.

The college encourages and supports lecturers participating in international conferences. From here, the idea of de-

veloping a curriculum for Science Education MA degree was derived, which includes three fields: material science, life science and mathematics for primary and post-primary education.

This is the place to announce that the professional committee of the Council for Higher Education (CHE) recommended to the subcommittee and plenary CHE to give the program full recognition. The CHE Committees adopted and approved the recommendation.

It is my pleasure to congratulate the scientific committee involved in the preparation of the special issue of "Daruna" and all those who lectured in the symposium and their contribution is presented in this special issue of the journal,



**Prof. Muhamad Hugerat
& Prof. Avi Hofestein**
**The Academic Arab College
for Education in Israel – Haifa**



Introduction

The State of Israel is one of the leading countries in investing in research and development in the various areas of science and technology. These stems from recognizing the importance of research in the development for the society, economy, and technology. This is highly based and aligned with belief that it will lead to a modern society and literate citizens who can deal with the challenges of our ever-changing world. In the last decade, Israel, a small country has been a 'laboratory' for several Nobel Prize laureates in Chemistry. This is highly based on the key idea that investing money in research and science is very important for the future of the country and its society. Any academic institution seeking to advance and succeed must promote and invest in research, in general, and in scientific research in particular.

There is no doubt that the subject of sustainability is a major issue nowadays. A basic and essential component of sustainability is the field of green chemistry, which gained a great momentum in recent years (from the 90's). Many institutions and researchers are pleased to investigate this important subject, among which, our institution stands "The Aca-

demic Arab College for Education in Israel- Haifa".

Regarding the symposium that took place during February, 2016 we decided to focus on two key topics namely green chemistry and sustainability. Clearly these two topics are interrelated and both are researched and developed for the improvement the standards of life of the world citizens.

It is suggested that these two interrelated topics should be integrated into the formal science education as well as in the courses provided in the colleges that prepare the future teachers in general and in our college in Haifa in particular. Education for Sustainable Development means including key sustainable development issues into teaching and learning; for example, climate change, disaster risk reduction, biodiversity, poverty reduction, and sustainable consumption. It also requires participatory teaching and learning methods that motivate and empower learners to change their behavior and take action for sustainable development. Green chemistry, also called sustainable chemistry, is an area of chemistry and chemical engineering focused on the designing of products and processes

that minimize the use and generation of hazardous substances. Where environmental chemistry focuses on the effects of polluting chemicals on nature, green chemistry focuses on technological approaches to preventing pollution and reducing consumption of nonrenewable resources. It should be noted that the years 2005-2014 were declared as the years for sustainable developments.

In this manner, chemists can have a major impact on human health and the environment. Production of such materials should be economic, in addition to being ecologically suitable. Many solvents are used every day in a variety of reaction in the manufacturing processes as solvents and thinners. One of the goals of green chemistry is to minimize the use of these solvents and reduce chemical waste accumulated in the industry and research institutions worldwide. Another goal is to give access to chemistry students in science teaching institutions and schools through waste reduction and reduction

of risks associated with using solvents and toxic substances in relatively large quantities.

This special issue of "Daruna" provides the readers (e.g. teachers and professional development providers) with an opportunity to read about recent research on these regarding sustainability and green chemistry, and its industrial applications and will highlight environmental and health aspects and implications for educational objectives in Israel and abroad. The research that began in the College discusses the importance of sustainability and green chemistry teacher trainees, teachers and students in post-primary schools.

To sum-up, one of the main goals for publishing this special issue of Daruna is to make the subject of green chemistry and sustainability in teacher training colleges as an integral part of the school science programs.

A Review of Nanotechnology Experiments with Environmental and Biological Applications

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Abstract

Nanotechnology has the potential to revolutionize medicine and improve human health. New nanomaterials can negatively affect the environment. Biology provides the key to securing these benefits while avoiding unwanted outcomes. Educating current students about the biological applications and environmental impacts of nanotechnology is necessary so that they can join the technological workforce of the future and make informed decisions as citizens about how to use nanotechnology. After a brief introduction to nanotechnology, we review nanotechnology experiments which highlight biological applications or illustrate the effects of nanotechnology on living organisms. These experiments are most appropriate for high school and college students. Educators will find this review useful for discovering new and interesting hands-on activities for their students.

Introduction to Nanotechnology

Everything that chemists synthesize in their laboratories and everything made by nature exists as atoms, each belonging to one of about 100 different elements. Until recently, anything new had to be made by mixing different combinations of atoms of these elements. Given the millions of possible combinations of atoms, one would think that this could satisfy our need for innovative materials. Recently, scientists discovered a new way to make well-known elements perform new tricks.

Our everyday experience tells us that a piece of gold has a yellow color. But if you divide it in half, and keep dividing it into smaller pieces, smaller than a grain of sand, smaller than a bacteria cell, and even smaller, gold begins to change. When size of the piece of gold is less than 100 nanometers (100×10^{-9} m), it changes color, melting point, chemical reactivity, and other properties. At the nanoscale, properties change with the size of the particle. If scientists can control the size of the particles, then they can control the properties of the particles, leading to an element behaving differently depending on the size of the nanoscale particles (nanoparticles). Entire industries, such as electronics, are undergoing

a revolution in their ability to offer new products at lower prices, higher quality, and greater functionality. Because of the many new features of nanosized materials, nano-enabled technology, or nanotechnology, there is an opportunity for our society to undergo another technological revolution, similar to the industrial revolution several hundred years ago and like the information technology revolution more recently (Roco, 2003a; Roco, 2003b).

Nanotechnology and Biology

Doctors may use nanoparticles in many ways to improve our health. The size of gold nanoparticles allows them to enter small spaces, such as within a patient's cancer cells. Once there, a doctor can heat the gold particles with radio waves, causing the cancer cell to decompose (Cherukuri & Curley, 2010). By using nanosized sensors, doctors can take diagnostic measurements more quickly and easily – a drop of blood from a pinprick replaces the need to draw blood from a patient's vein.

Since nanoparticles possess unique characteristics, there is justifiable concern that they could negatively affect our environment. What hap-

pens to flora and fauna in the event of an accidental release of nanoparticles into a river? The fate of nanoparticles depends not only on their size and composition but also the coating that surrounds the particles. Nanoparticles are often covered in a layer of other chemicals. This coating prevents them from sticking together and forming large, bulk particles with a loss of their unusual properties. Nanoparticles may agglomerate and precipitate, removing them from the water and accumulating in sediment. Coated nanoparticles may remain unreacted until environmental conditions change, such as when fresh water flows into an ocean. Certain aquatic plants can absorb nanoparticles readily, helping to filter them from the water. Harvesting these plants, known as phytoremediation, can be an effective way to remove nanoparticles or other toxins from the natural environment. Some plants or animals may have a low tolerance for particular types of nanoparticles, requiring an immediate intervention. Engineers and scientists, including the authors, are studying how nanoparticles affect the environment and how to minimize the harm caused by their release.

Nanomaterials are not only a man-made phenomenon. Many examples of nanoscale features exist in nature, including iridescent butterfly wings, structures of sea shells, sticky feet of the gecko, and water repellent surfaces on lotus leaves. With the tools used to analyze nanomaterials, scientists can now more fully understand how these plants and animals behave. They are beginning to design materials with similar features observed in nature (biomimicry). Of course, the molecules and processes within biological cells are the ultimate nanomachines, capable of synthesizing chemicals that are not reproducible in the laboratory. Nature can also contribute to nanoparticle synthesis. Scientists have discovered a wide variety of naturally occurring materials which provide inexpensive, environmentally sustainable, and easy to use ingredients for making nanoparticles.

Biological Nanotechnology and Education

Nanotechnology will affect the health and well-being of everybody and our natural environment. In order to minimize the adverse effects and promote the benefits of nanotechnology, students need to learn about nanotechnology in school. This will not only increase the number of future scientists with hands-on experience and knowledge of nanotechnology, but it will also create a well-informed public, capable of making decisions about how to use nanotechnology. This is a global challenge that involves educators on every continent. See a recent book, *Global perspectives of nanoscience and engineering education* (2016) to learn more about how nanotechnology is taught around the world and a chapter in the forthcoming 4th edition of the *Spring Handbook of Nanotechnology* (Winkelmann & Bhushan, 2017).

Education can take many forms. Students in primary grades can become familiar with the basic concepts of nanotechnology, such as size and scale, both those familiar to them as well as micro- and nanoscale objects too small to see with the unaided eye. As students enter secondary school, they can learn about nanotechnology in physics, biology, and chemistry classes. Many teachers feel that they do not have time in their busy curriculum schedules to add additional topics like nanotechnology. They can only add an activity if it specifically addresses the course's existing learning objectives. Given the multi/interdisciplinary nature of nanotechnology, this is frequently possible (Stevens, Sutherland, & Krajcik, 2009).

Nanotechnology curriculum materials are often designed for use in higher education classes, where the curricula are more flexible. Schools offer academic minors, majors, and certificate programs in nanotechnology (Nanoscale science and engineering education 2008; *Global perspectives of nanoscience and engineering education* 2016). Students may learn about individual nanotechnology topics within existing courses or in separate nanotechnology courses. The ad-

vantages of this approach are that no new classes need to be created and students learn about nanotechnology within the context of the course subject. An alternative is to create one or more separate courses specifically about nanotechnology. Students gain a deeper understanding of topics presented in those classes and if one course is successful, another nanotechnology course can be added to the curriculum. While most nanotechnology courses are designed for graduate school or undergraduate capstone experiences, some schools offer nanotechnology as early as the first year.

As an example, Florida Institute of Technology has taught a unique introductory nanotechnology laboratory course for over ten years (Winkelmann, Mantovani, & Brenner, 2008; Winkelmann, 2009a). Students perform a wide variety of experiments and gain hands-on experience using education-grade scanning tunneling and atomic force microscopes (STM and AFM). Many of the experiments are designed by the faculty who team-teach the course. Other experiments are adopted from those in the published science education literature. Topics include the design of solar cells, effects of nanoparticles on plants and bacteria, and engineering applications of nanoparticles. Students also learn about broader societal issues, such as the ethical use of nanotechnology. In that activity, students role-play characters involved in a debate about using nanotechnology to solve a problem in their community (Winkelmann, 2012). Lab experiments in the course are designed for students who have completed just their first semester of general chemistry.

Other schools offer classes with a greater focus on engineering, biology, chemistry, or physics. Students at a liberal arts school can learn about the way nanotechnology affects society (Porter, 2007) or the overlap between disciplines of nanotechnology and art (Bentley & Imatani, 2012). Nanotechnology education resources are freely available (Winkelmann, Bernas, & Saleh, 2014) and nanoparticle synthesis experiments are reviewed elsewhere (Winkelmann, 2009b). The

focus of this review is on nanotechnology experiments which also involve an aspect of biology or environmental science. The experiments described below can fit within a single nanotechnology laboratory course or they can be added to traditional science laboratory courses. Experiments could be altered to serve as classroom demonstrations or outreach activities. We have performed and taught most of the experiments described below.

Equipment and Safety

Many of these experiments are designed to be taught at the introductory level but could be simplified for teaching in a high school science course. Necessary equipment and safety issues may restrict the implementation of some experiments.

Color is an important property of nanoparticles due to the unusual way that it changes with particle size. The peak in an absorbance spectrum of a nanoparticle solution will shift to shorter wavelengths as the particle size decreases. Thus, it is a reliable estimation of the most common size of the nanoparticles. The width of the peak is also noteworthy because it indicates the range of nanoparticle sizes formed. A UV-visible spectrometer is a useful tool for quantitative absorbance measurements but a research-grade instrument is unnecessary. Education-grade spectroscopy instruments are appropriate, as are even less expensive colorimeters. The most economical method is comparing the nanoparticle solution color to standards. This approach is effective, for instance, for measuring the concentration of gold nanoparticles in dietary supplements (Campos et al., 2016).

Education-grade STM and AFM instruments can exceed the teaching laboratory budgets of many schools. Some research institutions offer remote access or remote viewing of these instruments and the images they collect. Many websites contain a catalog of these images for viewing any time. Other low-cost approaches which provide

hands-on simulations of these microscopes include Lego models (Lindell & Kähkönen, 2013; Schwenz & Pacheco, 2014) and other hands-on activities (University of Wisconsin - Madison MRSEC Education Group, 2016).

Other advanced characterization techniques, such as transmission electron microscopy (TEM), and dynamic light scattering (DLS) can be used to characterize the nanoparticles. Use of these instruments can change an experiment designed for a first-year course into an upper-level laboratory activity.

Safety is always a paramount concern in the laboratory. Chemicals, biological specimens, and nanomaterials pose their own individual safety concerns. For all experiments described in this chapter, it is assumed that students will wear appropriate eye protection and laboratory coats or aprons. Gloves are recommended. Instructors should read all safety information for the materials they are handling and make students aware of all hazards. When working with bacteria, use non-infectious strains. Nanoparticles are more hazardous when in the solid phase compared to the solution phase. Powders can more easily enter the body through the lungs. Unless absolutely necessary, the authors recommend leaving nanoparticles dissolved in solution. Follow all regulations when disposing of chemical and biological waste.

Synthesis of Nanoparticles Using Natural Products

Metal nanoparticles, especially those of gold and silver, can easily form by reducing metal cations with a wide variety of organic and biological reducing agents. Proteins, amino acids, carbohydrates and natural products react with metal cations to form nanoparticles with different sizes, shapes, and morphologies. Often, the reductant coats the nanoparticles, increasing their stability through electrostatic or steric repulsion. Most of these synthesis methods are designed to be completed in a two- or three-hour lab period, and can

be adapted to the high school classroom as needed. The syntheses are considered to be examples of green chemistry, as the methods used to make nanoparticles use renewable materials and aqueous solutions at low temperatures.

Silver nanoparticles can form using tea, coffee, honey, juice, wine, and vinegar in introductory undergraduate labs, including courses for non-science majors (Metz, Sanders, Miller, & French, 2014). Students react small volumes of silver nitrate with one of these reductants at room temperature. The reaction is complete after 30 minutes so students can measure the absorbance spectrum of the nanoparticles. Particle size is typically 50 - 75 nm in diameter and the solution has an absorption peak between 445 and 480 nm, depending on the reductant used. A similar, upper-level undergraduate synthesis of silver nanoparticles with honey is also described (Paluri et al., 2015). A dilute solution of honey is heated with silver nitrate, stirred for 30 mins and the absorbance spectrum is recorded. The peak wavelength is 420 - 440 nm.

Gold nanoparticles form using tea leaf extractions as a reducing agent (Sharma, Gulati, & Mehta, 2012). Tea leaves are extracted in water by stirring vigorously then filtering. Tetrachloroauric(III) acid is added to the solution and within 15 mins, the solution turns purple, indicating the formation of gold nanoparticles. The gold nanoparticles are 20 - 25 nm in diameter and exhibit an absorbance peak at 530 - 563 nm. An upper-division undergraduate adaptation of this procedure uses inquiry-based learning to compare green and non-green syntheses of silver and gold nanoparticles (Paluri et al., 2015).

Plant leaves can also reduce gold and silver cations to nanoparticles. An undergraduate lab procedure describes the reduction of silver by geranium leaves (Richardson et al., 2006). Geranium leaves are cut up and briefly boiled in water, then the solution is centrifuged and filtered. A small volume of extract is added to a silver nitrate solution and heated. The particles have an absorbance peak at 415 nm. Particle diameters range

from 15 to 45 nm. The lab is designed for high school or first-year undergraduate students.

Impact of Nanoparticles on Microorganisms

Silver nanoparticles are commonly used as anti-microbial and antibacterial agents. Experiments demonstrate the toxicity of silver nanoparticles and show their medicinal applications. Students synthesize silver nanoparticles using common reduction methods and expose these particles to yeast cells or bacteria cultures. These experiments are designed for high school chemistry and biology classes or first year undergraduate lab courses.

In a high-school level biotoxicity experiment, students synthesize silver nanoparticles using a sodium citrate reduction method (California NanoSystems Institute, 2012). Silver nitrate and sodium citrate solutions are mixed and heated until a faint yellow color is observed, indicating that very small silver nanoparticles are forming. The particles cool to room temperature and the UV-visible spectrum is recorded. The solution has a peak absorbance around 410 nm and the nanoparticles are 4 nm in diameter. Solutions are prepared containing water, silver nanoparticle solution, and dextrose in a filtration flask. Baker's yeast (*Saccharomyces cerevisiae*) powder is added to the flask then the flask is sealed with a stopper. A hose connects the flask to an inverted graduated cylinder in a bucket of water (figure 1) or a manometer, which is used to measure the volume of carbon dioxide released by the yeast. Silver nanoparticles are toxic to many types of organisms so there is a change in the rate of cellular respiration when silver nanoparticles are present. The volume of carbon dioxide released is measured for 30 mins. Students can conduct a control experiment using no silver nanoparticles to observe the respiration of healthy yeast cells. Additional studies of silver nanoparticle biotoxicity using the yeast respiration experiment were performed by our group. We prepared silver nanoparticles using other common reduction methods found in the literature. Nanoparticles



Figure 1: Arrangement for silver nanoparticle-baker's yeast biotoxicity experiment.

with different coatings and sizes were tested, including 12 nm particles coated with borohydride (Mulfinger et al., 2007), 40 nm particles prepared via the Tollens reaction (Soukupova et al., 2010), and a silver colloid claiming to contain 1 - 10 nm silver particles coated in a protein sold by Natural Path Silver Wings. None of the nanoparticles had any significant effect on the yeast respiration, indicating that silver nanoparticle toxicity is dependent on the size and coating of the particles with the smallest citrate-coated nanoparticles being the most effective. Thus, while many methods exist to make silver nanoparticles, only the citrate reduction method formed silver nanoparticles which show any efficacy towards the baker's yeast. It was also observed that high silver cation concentrations are toxic to baker's yeast. Silver nanoparticles can also slow or prevent bacteria growth. Students can prepare cultures with bacteria and exposed them to silver nanoparticles. Results are evident within one week (Gardner & Jones, 2009). Petri dishes are prepared with agar nutrient broth beforehand. Students collect bacteria colonies from common household places for both treatment and control plates. Instead of

synthesizing nanoparticles themselves, students swab the plates with a silver nanoparticle-coated metal hook, called a handler, which is used in place of a hand to touch bacteria-contaminated surfaces (e.g., toilet handles and door knobs). Plates are incubated for one week and the number of colonies on the treatment and control plates are counted and compared. The nanoparticles which rubbed off of the handler's surface onto the agar cause a significant decline in bacteria population. This experiment is especially appropriate in cases when chemicals or laboratory equipment is not available.

A high school level lab experiment introduces students to silver toxicity by exposing *E. coli* and Baker's yeast to silver nanoparticles (National Nanotechnology Infrastructure Network, a). The experiment requires three class sessions, including a day to prepare practice plates using gelatin. The teacher prepares a silver nanoparticle solution and petri dishes with agar in advance. The students prepare control plates for each microorganism, as well as diluted silver nanoparticle solutions. Plates are incubated for up to two days at room temperature or for one day at 37 °C. The students analyze their results in groups and discuss the effectiveness of silver as an antimicrobial agent.

Similar high school experiments can be performed in 3 or 4 class sessions to demonstrate the effects of silver on bacteria species. The teacher prepares agar plates in advance. Students synthesize silver nanoparticles in class then expose *E. coli* to different concentrations of silver nanoparticles in duplicate, and count the numbers of colonies growing on agar plates (National Nanotechnology Infrastructure Network, 2012a). The students also expose plates to soap and other common disinfectants to compare the effectiveness of silver nanoparticles versus household cleaners. These results are compared to the control solutions, grown in media broth.

Silver is used in bandages as an antimicrobial source. Students can compare the effectiveness of bacteria growth on bandages (National Nano-

technology Infrastructure Network, b). Bacteria (*Micrococcus luteus* or *Staphylococcus epidermis*) are exposed to bandages without silver, and students create the following treatment groups: a control, a treatment with a common disinfectant, and a silver nanoparticle treatment (synthesized by students or purchased from a commercial source). A commercially available bandage manufactured to contain silver particles is also studied. Students cut the pads out of the bandages and place them in a petri dish. Then, students use a cotton swab to spread bacteria around the plate and incubate the plates for one day at 37 °C. Students measure the zone of inhibition around the bandage and record data and observations.

A similar experiment can be performed with socks, in which students prepare silver nanoparticles by a sodium citrate reduction method then cut 5 cm square pieces of socks and soak in solutions of silver ions, nanoparticles, or other disinfectants (National Nanotechnology Infrastructure Network, c). These socks are then placed in petri dishes (prepared by the teacher) and students add bacteria to the plates. The plates are incubated for a day at 37 °C and students observe inhibition of bacterial growth the next day.

Impact of Nanoparticles on Plants

The impact of silver nanoparticles can be examined in both aquatic and terrestrial plant life. Experiments are designed for high school and first-year undergraduate students to showcase the negative effects of nanoparticles. A second part to the silver nanoparticle synthesis using juice, wine, coffee, etc. discussed previously demonstrates the effects of silver nanoparticles on a terrestrial plant, Wisconsin Fast Plants (*Brassica rapa*) (Metz et al., 2014). Potted plants were exposed to nanoparticle solutions multiple times per week for up to one month. Students measure the plant heights every few days. The plants are then digested in concentrated nitric acid and inductively coupled plasma instrumental techniques are used to determine the amount

of silver absorbed by the plants. Results show that nanoparticles formed using various food ingredients as reductants have varying effects on plant growth.

A similar experiment demonstrating silver nanoparticle toxicity has been developed for high school students by exposing fresh water plants (*Elodea* or *Egeria* sp.) to commercial colloidal silver (National Nanotechnology Infrastructure Network, 2012b). Students expose the plants in test tubes with water (no soil) and solutions of colloidal silver for a day and make observations during the next class period. Students can also synthesize silver nanoparticles in class and expose the plants to them. Our group has developed a similar lab experiment for first-year undergraduate students by growing *Egeria densa* (Brazilian *Elodea*) in silver nanoparticle solutions. Silver nanoparticles are synthesized using a citrate reduction method and characterized using UV-visible spectroscopy (California NanoSystems Institute, 2012). Particles are 4 nm in diameter and coated with citrate ions. Stalks of *E. densa* are grown in large test tubes with dilute silver nanoparticle solutions for 1 week in a greenhouse. The stalks are then dried in an oven and leaves are removed from the plant. The leaves are ground in cold ethanol and a UV-visible spectrum is recorded to calculate chlorophyll a and b concentrations (Lichtenthaler, 1987). In experiments run with silver nitrate controls, the silver cations showed a greater impact on the plants compared to the same concentration of silver nanoparticles.

Nanosized silver is by no means the only material which can harm plants. In a simple experiment designed for high school and undergraduate students, engineered nanoparticles of SiO₂ and ZnO are added to a dish containing water and mung beans (Ross, Owen, Pedersen, Liu, & Miller, 2016). Both compounds caused a noticeable lack of growth in the beans, with the zinc oxide nanoparticles showing the greater toxicity. Beans kept in a dish of water sprouted significantly longer stems and more leaves. Students can see dif-

ferences in the rate of growth after less than one week. No instrumentation is necessary for the experiment; students simply measure the length of the stems using a ruler. To learn more about the nanoparticles, students also receive an image of the particles collected by a scanning electron microscope (SEM) then use imaging software to measure the range of particle sizes. By seeing the small sizes of the nanoparticles, students can begin to understand how the nanoparticles enter the bean and affect its growth.

Impact of Nanoparticles on Animals

The impact of nanoparticles on animals can be assessed using viability assays to determine mortality after exposures for 24-72 hours. Students start with an initial number of organisms in an ecosystem and expose them to nanoparticle sources, count the number that are no longer viable over time, then report this data. Silver sources can be purchased from suppliers or students can synthesize silver nanoparticles using common procedures such as those previously mentioned. Copepods (*Daphnia* sp.) are a common freshwater crustacean used in toxicity tests. Students can expose copepods to different concentrations of silver nanoparticle solutions and perform viability tests over a 3-day period (Centre for Mathematics, Science and Technology Education, 2016). The effects of silver nanoparticles, micron-sized silver particles, and silver cations can all be studied. Students can also calculate the LD₅₀ (concentration of silver which is deadly to 50% of the population of organisms).

Similar to the copepod experiment, high school students can expose California blackworms to different concentrations of commercial colloidal silver to determine viability (National Nanotechnology Infrastructure Network, 2012b). The experiment measures the toxicity of silver after a 24 hour period and provides teacher resources for a 3-day lesson about the ecosystem and aquatic food chain.

A third experiment exposes synthesized silver

and gold nanoparticles to brine shrimp for an interdisciplinary science lab that can be used for high school or first-year undergraduate courses (Maurer-Jones et al., 2013). Students can synthesize gold nanoparticles through a sodium citrate reduction and silver nanoparticles through a sodium citrate or sodium borohydride reduction. Alternatively, the instructor can prepare stock solutions of nanoparticles and students can dilute those. Students expose the brine shrimp to different concentrations of nanoparticles in well plates over a 24 hour period. The percent viability is then measured based on shrimp moving when exposed to a light source. The teacher instructions provide a way for students to expose shrimp for two to three days in an inquiry-based experiment.

Nanoparticles as Biosensors

The reduction of metal cations to nanoparticles can be used to observe different biological processes based on the redox reactions involving biomolecules. For example, gold(III) ions are reduced to gold nanoparticles by hydrogen peroxide in the oxidation of glucose by the enzyme glucose oxidase (Bai et al., 2009). The reduction of gold can be measured at 540 nm. The peak intensity is proportional to the enzymatic activity. Students also measure the change in the concentration of the nanoparticles with respect to different concentrations of either glucose or hydrogen peroxide. This experiment is suitable for analytical chemistry courses because students use a standard curve to measure glucose concentration and determine the molar absorptivity of the glucose sensor.

Measurement of glucose in blood can be adapted for a high school biology or chemistry experiment (National Nanotechnology Infrastructure Network, d). Students measure the glucose concentration in synthetic blood and urine samples using blood glucose monitoring kits. Commercially available kits include the necessary materials for measurements, including glucose standards and test strips. The teacher must prepare

different glucose solutions to simulate urine and blood, using food coloring. The glucose meter measures a fluorescence signal from carbon nanotubes, which should be explained to students when introducing the experiment.

Nanoparticles in Land and Water

High school students can create models using clay to demonstrate how easily nanoparticles migrate from land to the ocean and waterways (National Nanotechnology Infrastructure Network, e). Using commercial water testing kits, students measure pH, nitrates, ammonia, and nitrites in DI water. Students create a clay mountain in large tray, and add fertilizer to simulate nanoparticles. Water is then pipetted down the mountain, into the tray, demonstrating runoff. The students then measure the properties of the contaminated water, simulating the effects of nanoparticles, and indicate differences in water quality. The lab can be followed up with experiments demonstrating the toxicity of nanoparticles to aquatic and terrestrial life, including plants and animals (National Nanotechnology Infrastructure Network, 2012b).

Nanotechnology plays a role in cleaning a contaminated environment. Iron nanoparticles can reduce water pollutants while the iron is oxidized to rust. Students can synthesize iron nanoparticles by reducing iron chloride in the presence of sodium borohydride (Winkelmann et al., 2011). The nanoparticles are stable long enough for students to mix them with a dye, which represents the pollutant. Students monitor the solution's absorbance as the color fades. A graph of absorbance vs. time reveals the rate of the reaction. Students can also react the dye with micron-sized iron particles to see how the particle size affects the reaction rate. Larger particles have less surface area per gram so the reaction proceeds more slowly. While a faster reaction is typically more desirable when cleaning the environment, students might also consider the cost, time, and effort involved in preparing the nanoparticles. Larger particles are less expensive. There are

tradeoffs to consider, leading to no clear, correct answer but this creates a realistic scenario involving the use of nanotechnology.

Nanotechnology and Biomimicry

Many biological systems have nanoscale adaptations that help them survive. For example, sharks have a nanoscale pattern on their skin that acts as an antifungal and antibacterial agent. Another example of nanoscale adaptations is seen in lotus leaves, which have a hydrophobic coating that allows the leaf to repel water. A high school lab experiment demonstrates that commercially available materials possess the same hydrophobic properties as biological organisms, which makes the surface self-cleaning in aquatic environments (TeachEngineering, n. d.). The experiment compares the plant leaf to a nano-fiber cloth that mimics the process occurring on the lotus leaf surface. Students can scratch or cut the cloth and evaluate its performance.

Conclusions

Nanotechnology is a broad, interdisciplinary field that yields a wide range of applications in electronics, medicine, consumer goods, construction materials, agriculture, and others. As with any technology, we should weigh these benefits against issues related to its sustainability and environmental impact. Since many new uses of nanotechnology will be developed in the near future, today's students must learn about nanotechnology and how it affects the world around us. This will not only inspire the next generation of scientists and engineers but also create a scientifically literate general public who will choose how they want to use nanotechnology.

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Relevant Chemistry Education for Sustainability*

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Abstract

This chapter elaborates on three commonly suggested concepts used in the rhetoric for educational reform in science education. One suggestion is to raise the relevance of science education. Up until now, the word 'relevance' in the science education literature has often been used with high degrees of uncertainty and ambiguity. Thus as the first concept, this paper presents a model for a comprehensive understanding of the meaning and dimensions of relevance in science education. Secondly, we will revisit the concept of the two visions of scientific literacy and suggest that there is a further, third vision needed for relevant chemistry education. A third input is the adoption of the philosophy of Education for Sustainable Development into science education. Some very recent ideas will also be presented for this area. The chapter elaborates on the connections of the three concepts when it comes to providing guidance for chemistry curriculum reform. Two illustrative cases from Germany and Israel will show how chemistry teaching can come up with the elaborated stages of all the three concepts to make chemistry learning relevant education for sustainability.

Introduction

'Relevance' belongs to the most oft-used key terms when it comes to reforms in science education. Teachers are asked to make their teaching 'more relevant' to avoid a loss in student interest and motivation. However, the term is often used with high degrees of uncertainty and ambiguity (Newton, 1988b). An analysis of the science education literature shows that there are various meanings when the term is used. The literature also shows different dimensions of relevance when it comes to science education: individual, societal and vocational relevance (Stuckey, Hofstein, Mamlok-Naaman & Eilks, 2013). The review by Stuckey et al. (2013), as well as the perspective paper by Hofstein, Eilks and Bybee (2011), suggest that the societal dimension is often the most neglected of the three. However, a stronger societal focus within science and chemistry education also can be justified by many different theories. Among these, are the concept

of scientific literacy (Roberts, 2007) and the ideas of Education for Sustainable Development (ESD) (Burmeister, Rauch & Eilks, 2012). This paper will discuss all the three frameworks (relevance; scientific literacy; ESD) and try to identify whether and in which degree they overlap in guidance for chemistry education curriculum reform. This will be illustrated by two classroom examples from Germany and Israel.

Three suggested frameworks for educational reform in chemistry education

Understanding the meaning of relevance in science education

'Relevance' is a frequently used term when educational reforms are conducted. Teachers are supposed to provide students with 'more relevant' education in order to motivate them and make them curious about science (Holbrook, 2005). However, it is not always clear what is meant by making science education 'relevant'

and how to do it. Twenty-five years ago Newton (1988a) wrote:

The notion of relevance is not a simple one. It seems at the least unhelpful and at the worst counterproductive to urge a teacher to be relevant in terms which are abstract and diffuse. It might be useful if some aspects of the notion of relevance were to be clarified. (Newton, 1988a, p. 8)

A recent analysis of the literature showed that the term 'relevance' is still used in widely differing contexts and incorporates many different meanings and concepts (Stuckey et al., 2013). For example, relevance is used in the sense of taking interest in something (Holbrook, 2008), as a perception of meaningfulness (Westbroek, Klaassen, Bulte & Pilot, 2003), or as having positive consequences for promoting learner motivation (Keller, 1987). The term is connected to individual interest, but also includes future careers (European Commission, 2004) and real-life impacts on individuals and society (Stolz, Witteck, Marks & Eilks, 2013), e.g. in terms of growing prosperity and sustainable development (Knamiller, 1984). Only sometimes, relevance is explicitly stated to be multidimensional (Rannikmäe, Teppo & Holbrook, 2010; Stuckey et al., 2013).

One of the key questions regarding relevance is what exactly is considered to be relevant, to whom, at what time, and/or who decides. By looking for answers to the question: 'Who decides what is relevant?', Aikenhead (2003; 2006) gave seven different heuristic categories of experts (that might overlap to varying degrees), which include academic scientists, curriculum policy makers and researchers, science-based industry stakeholders, mass media and Internet representatives, economics and health experts, players in the area of cultural aspects, and students.

Because the term relevance has different meanings and because various contributors make widely differing suggestions as to what constitutes relevant science education, the concept also

has different facets and dimensions. Aspects of what relevant science education is (or isn't) can be obtained from definitions of the general aims and orientations of education, as well as from within science education itself. Many theories can be used to derive issues which should be considered relevant science education. Among them are general theories like 'Allgemeinbildung' or 'Activity theory' as well as more science education-specific concepts like Scientific Literacy for All (cf. Stuckey et al., 2013). For example, Holbrook (2005) suggested various important aspects which need to be taken into consideration in order to raise the relevance of science education. These include the personal lives of the students, the workplace of the future, and its relationship to and status within society. Similar dimensions also exist in many older documents from the 1980s onwards, which suggest organizational schemes for making science education more relevant (see Harms & Yager, 1981; Hofstein & Yager, 1982; Schollum & Osborne, 1985; Newton, 1988b).

Summing up all the literature covering almost 50 years, Stuckey et al. (2013) suggested a definition for the term relevance and a corresponding model of its dimensions. This definition is connected to the ideas of consequences and fulfilling personal needs:

- *Science learning becomes relevant education whenever learning will have (positive) consequences for the student's life.*
- *Positive consequences can include:*
 - *Fulfilling actual needs related to a student's personal interest or educational demands (of which learners are aware),*
 - *as well as The anticipation of future needs (of which students are not necessarily aware).*
- *Relevance in science education covers both intrinsic and extrinsic components. The intrinsic dimensions encompass student's interests and motives; the extrinsic dimension covers ethically justified expectations of one's personal environment and the by the society in which they operate and live.*

Relevance can be considered to consist of three different dimensions: individual, societal and vocational. For science teaching, this means that relevant education must contribute to pupils' intellectual skill development, promote learner competency for current and future societal participation and address learners' vocational awareness and understanding of career chances. Each of the three dimensions encompasses a spectrum of present and future aspects. (p. 19)

The analysis revealed three dimensions of the meaning of 'relevance' in science education:

- *The individual dimension: the relevance of science education for the individual encompasses matching the learners' curiosity and interests, providing students with necessary and useful skills for coping with their everyday lives today and in the future, and contributing to the development of intellectual skills.*
- *The societal dimension: the relevance of science education from the societal viewpoint focuses on preparation of pupils for self-determination and a responsibly led life in society by understanding the interdependence and interaction of science and society, developing skills for societal participation and competencies for contributing to society's sustainable development.*
- *The vocational dimension: the relevance of science education in the vocational dimension is composed of offering orientation for future professions and careers, preparation for further academic or vocational training and opening up formal career chances (e.g. by having sufficient coursework and achievements to enter into any given higher education programme of study). (Stuckey et al., 2013, p. 18)*

Figure 1 suggests an illustrative model encompassing the three dimensions of relevance in science education. Each dimension covers extrinsic and intrinsic components as well as a range from present to future for the relevance of learning science. The three dimensions of the model are not

solitary or hierarchically arranged. The dimensions overlap and many aspects can contribute to more than one dimension with respect to how they are interpreted and executed. For example, career orientation can be part of vocational relevance, but it may also link to personal curiosity or respond to a demand for more scientists, which enables prosperity for the society's future.

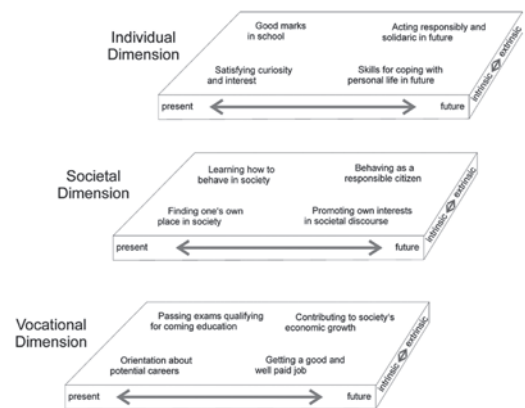


Figure 1. Model of relevance in science education (Stuckey et al., 2013)

The value of the model in Figure 1 was validated through focus group discussions with student teachers, trainee teachers, teachers, and science educators (Stuckey, Sperling, Mamlok-Naaman, Hofstein & Eilks, 2014). The participants suggested that this model can be a beneficial tool for reflecting upon curricula, textbooks, and teaching practices. The curricula and teaching examples which were evaluated as the most promising for promoting relevant science education were those that address all three dimensions at once. However, it is also important to maintain a good balance between them and keep them aligned with the lesson's target audience.

Based on reflections on different basic curriculum orientations in science education, this paper suggests that secondary science education is best served by socio-scientific, issues-based science curricula (Sadler, 2011), when attempting to cover all three dimensions in an integrated way. This potential can be further improved by opening the

pedagogy to societal practices and including references from the fields of industry and science-related professions.

A Vision III of scientific literacy

In 2007, Doug Roberts suggested two different visions of scientific literacy. In Vision I, the more traditional one, science learning in general and chemistry education in particular focuses first of all on learning content and concepts for later application. This approach was and is often organized along the inner structure of the academic discipline and mirrors traditional academic chemistry textbooks. For more meaningful education, Roberts suggested a more student-oriented vision, namely Vision II. He suggested that Vision II should focus on providing the learner understanding about the usefulness of scientific (chemistry) knowledge in life and society by starting science learning from meaningful contexts. Aikenhead (2006) connected the tension between the two approaches to different understandings of science education between ‘pipeline science – preparing future scientists’ and ‘science for all’.

More recently, Sjöström and Eilks (2017) discussed that some scholars, inspired by the idea of education for more sustainability, have suggested that there should be a third vision, namely Vision III. Vision III is a humanistic and critical approach; it emphasizes science learning for scientific engagement (Liu, 2013; Yore, 2012) and ‘knowing-in-action’ (Aikenhead, 2007). Science education according to Vision III aims at strengthening the learning beyond the knowledge of chemistry content, contexts, and processes. It argues for general skill development via contention with issues of chemistry that are relevant for a sustainable development of our society and the global world. Sjöström, Eilks and Zuin (2016) discussed this approach with reference to the green chemistry movement. They ended up their discussion with sketching the philosophical foundation of what they call ‘eco-reflexive science education’.

Figure 2 provides an organizer to understand the difference of Vision III from Visions I and II. It is developed based on Sjöström (2013), Sjöström and Talanquer (2014), and the visions I and II of scientific literacy by Roberts (2007). Where Visions I and II focus on content and contextualized knowledge and how it is applied in everyday life and Science-Technology-Society contexts, Vision III aims on critical skills development for actively shaping the future society in a sustainable fashion (Sjöström & Eilks 2017; Sjöström et al., 2016).

A Vision III based approach of chemistry education asks for educating critical and active citizens that take responsibility and act accordingly. Vision III asks for them in both communities, among the scientists and the non-scientists (Eilks et al., 2017). It is suggested that content knowledge of chemistry and contextual understanding about chemistry are necessary pre-requisites to participate informed in scientific and societal discourses on the technological applications of chemistry and its corresponding effects on the environment and society. However, it is also clear that this will not be enough. A critical stance is also needed that promotes understanding of the responsibility of any individual and in the same time directs the individual to act accordingly in society.

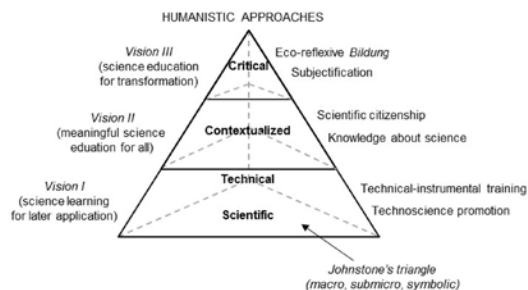


Figure 2. Three visions of scientific literacy (Sjöström & Eilks, 2016; Sjöström et al., 2017).

Sjöström and Eilks (2017) suggest that for preparing the young generation to actively participate in societal discourse and decision making,

teaching about those socio-scientific issues (SSIs) is needed that are relevant for sustainable development of our society, today and in the future. Chemistry education needs to take into account multi perspectives on chemistry related issues including their ecological, economic, and societal impacts (Burmeister et al., 2012; Sjöström, 2013; Sjöström, Rauch & Eilks, 2015). Especially so called ‘hot-type’ SSIs are of potential to provoke a critical view towards development in science and technology (Simonneaux, 2014). Hot-type SSIs can be characterized by their authenticity and controversial perception in society (Stolz et al., 2013). Examples are alternative materials, renewable energy supply, nanotechnology, or use of new dyes, cosmetics, or pharmaceuticals. All of these can provide chances and benefits, but can also cause risks. Pedagogies are needed in chemistry education where students learn how to argue, how to use scientific evidences to inform the public, and how corresponding information can be obtained, and also how careful respective information needs to be evaluated and used (Sjöström et al., 2015). This is the case for school education for all learners, but it should be also the case for the next generation chemists educated in our universities (Eilks et al., 2016).

Education for sustainable development and science education

The emphasis of education for sustainable development (ESD) was suggested by the Agenda 21 at the United Nations Conference on Environment and Development (UNCED) conducted in Rio de Janeiro, Brazil, in 1992. More specifically, chapter 36 of Agenda 21 claims the following: *Education is critical for promoting sustainable development and improving the capacity of the people to address environment and development issues. While basic education provides the underpinning for any environmental and developmental education, the latter needs to be incorporated as an essential part of learning. Both formal and non-formal education is indispensable to*

changing people's attitudes so that they have the capacity to assess and address their sustainable development concerns. It is also critical for achieving environmental and ethical awareness, values and attitudes, skills and behavior consistent with sustainable development and for effective public participation in decision-making. To be effective, environment and development education should deal with the dynamics of both the physical/biological and socio-economic environment, and human (which may include spiritual) development should be integrated in all disciplines and should employ formal and non-formal methods and effective means of communication.

The central focus of ESD is preparing the younger generation to become responsible citizens in the future. Students should be able to participate in a democratic society and to help in shaping future society in a sustainable fashion. They should learn to take responsibility for both themselves and future generations, based on the concept of sustainable development (de Haan, 2006).

There are different models of ESD. Nevertheless, most of these models contain some essentials in common. With respect to Paden (2000), McKeown (2002; 2006), UNESCO (2005), or De Haan (2006) the essential elements of most ESD models can be identified as:

- Learning about natural and man-made environments using an integrated view of their social, political, ecological and economic (and possibly cultural) dimensions, including involvement at the local and global levels;
- Focusing on participatory learning while aiming to promote citizenship skills through an ethics- and values-driven approach;
- Orienting learning on system-based thinking, including the use of interdisciplinary, learner-centered, experiential, and inquiry-based methods;
- And focusing on life-long learning as a perspective which integrates formal and informal education.

All ESD models suggest a thorough orientation

on societal issues, an interdisciplinary approach and a change in pedagogy far outstripping a simple re-arranging or altering of curricula. In this context, interdisciplinary means bringing together the different perspectives towards a societally relevant question incorporating chemistry, biology and physics, but also includes combining these with aspects from the economy, the social sciences, and the humanities (i.e. ethics). ESD approaches also demand implementing a skills-oriented teaching paradigm in the above-mentioned sense of an education for sustainable development which goes beyond education about sustainable development (McKeown, 2006). In his conclusion, Wheeler (2000) expressed hope that students will develop skills and personally act on both the individual and community level. This includes developing:

- *A deep understanding of complex environmental, economic, and social systems;*
- *Recognition of the importance of interconnectedness between these systems in a sustainable world;*
- *And respect for the diversity of 'points-of-view' and interpretations of complex issues stemming from cultural, racial, religious, ethnic, regional, and intergenerational perspectives. (p. 5)*

Since science - especially chemistry and the industries related to it - are at the economic heart of every developed society (Bradley, 2005), science education is given a core role in ESD (Burmeister et al., 2012). In a recent review Burmeister et al. (2012) analyzed potential ways for integrating chemistry and science education into ESD. Four basic strategies were identified, here described in brief:

- Mode 1: Green chemistry principles are applied to laboratory practices used in teaching and learning of science.
- Mode 2: chemistry learning is contextualized by applications of sustainable science and technology practices.
- Mode 3: Socio-scientific issues become the driver for chemistry education, e.g. climate

change, energy issues, risks and chances of products or processes, or environmental considerations.

- Mode 4: ESD becomes the driving force for school life's development, e.g. project work or networking schools with research and industry.

From the analysis provided by Burmeister et al. (2012), all four models can contribute to learning either about or for sustainable development. However, each of them would do so to a different degree and with variations in focus. Table 1 shows the estimated potential of each of the four basic modes for contributing to ESD. It also differentiates between learning about sustainable development, learning for sustainable development, and directly contributing to sustainable development, because of imminent changes in social, ecological or economic practices.

A balanced implementation and combination of the four modes might actually represent a promising strategy for achieving a broad range of ESD goals in science education. However, the four modes can also be considered as hierarchical distinctions, with the later modes including essential elements of the earlier ones. From this point of view, modes 3 and 4 seem to hold the most promise with respect to ESD as education *for* sustainable development (Burmeister et al., 2012). This would mean an SSI-based approach to science teaching with changes in the school culture, e.g. opening school life to societal areas like industry and science-related businesses. This would be the same conclusion as reached in the discussions of the relevance of science education and the Vision III for scientific literacy in the previous sections.

Potential for ...	Mode 1	Mode 2	Mode 3	Mode 4
... learning <i>about</i> sustainable development.	o	++	++	+
... learning <i>for</i> sustainable development.	-	-	++	++
... directly <i>contributing to</i> sustainable development.	o	-	-	+

Table 1. Reflection on the potential of the four basic models for dealing with ESD in Chemistry education (- = low; o = medium; + = high; ++ = very high)

Two classroom examples from Germany and Israel

In this section we will present two evidence-based developed teaching and learning modules from chemistry education in Germany and Israel. Both examples combine a focus on all the three dimensions of relevant science education, they aim on general educational capabilities and skills for societal participation, and both examples can be understood as ‘hot-type’ socio-scientific issues as they are suggested following the three theoretical approaches discussed to be of the most potential to implement ESD for more relevant and skills oriented chemistry education for sustainability.

Bioplastics or conventional plastics – an example from Germany

Recently, Burmeister and Eilks (2012) presented a lesson plan for chemistry education in Germany structured around ESD philosophies. The lesson plan follows the socio-critical and problem-oriented curriculum model for science education as described by Marks and Eilks (2009). The lesson starts with a textual approach based on excerpts from authentic, controversial magazine reports and brochures covering the use of conventional plastics, comparing them with emerging environmental problems, and suggesting bioplastics as an alternative. The material provokes questions about the basic chemistry of polymer materials as well as implications of their use, and also leads into questioning the value of their use with an eye towards ecological, economic and societal implications.

Students respond to this challenge by first learning the basic chemistry concepts behind the various kinds of plastics. Afterwards, however, they will revisit how this knowledge helps them in understanding the societal debate about conventional plastics and bio-plastics. A simple concept of sustainability is introduced to start reflection on different plastics (and their uses) with respect to ecological, economic and societal implica-

tions. This leads into a new pedagogical method called the product testing method (cf. Burmeister & Eilks, 2014). In this method the students perform as employees in a professional product testing agency. They compare different kinds of plastics: polyvinylchloride (PVC), polyethylene terephthalate (PET), and thermoplastic starch (TPS). Each of these plastics has individual advantages and disadvantages. The use of PVC is widely disputed in society, mainly because of certain plasticizers which are used in its production and problems with environmentally friendly recycling and storage of PVC waste. On the other hand PVC is very stable, has fantastic physical properties and can be easily and quite cheaply produced. In contrast, PET is viewed quite neutrally in the public debate. Nevertheless, discussions exist because of the serious environmental and social problems associated with the recycling process. It should be noted that PET waste is often exported to Third World countries with very low social and environmental standards. TPS as a biodegradable polymer usually enjoys very positive reviews in the popular press. However, TPS remains so far, expensive and has extremely limited potential for widespread application. To conclude, all the plastics have advantages and disadvantages which must be taken into account when a holistic evaluation is undertaken.

Pupils learn about the various advantages and disadvantages of each sort of material. A worksheet familiarizes learners with the different perspectives such an evaluation can encompass (Figure 3). These range from the economic aspects of production to availability and consumer friendliness issues to ecological concerns about production processes and waste removal in the context of ‘green chemistry’. It also asks them to weight the importance of the different dimensions. The students have to negotiate weighting factors between the different dimensions of a potential evaluation, namely physical properties, ecological, economic and social impacts. Then the students evaluate the pros and cons of their specific sort of plastic.

M2 Evaluation Sheet

Plastics		My weighing factor	My weighing factor of the pros	My weighing factor of the cons	My assessment of the expert group	Assessment of the mixed group
Evaluation criteria						
Plastic						PVC TPE PET
Green Chemistry						
Production and use without dangers for humans and environment						
No problems for disposal or recycling						
Production primarily from renewable resources						
Low energy costs for production						
Consumer and social interests						
Production, use and reuse take place according to West European social standards						
Safe usage for humans and animals also in the case of improper use (burning, swallowing, etc.)						
Products available cheaply everywhere						
Economy and industry						
Industrial production possible without subsidies						
Good marketability						
Recycling possible						
Material characteristics						
Good durability and long lifespan						
Good material properties and a broad area of usage						
Decision			100%			
Decision from the entire class						
Evaluation key:						
++ = very good (1) + = good (2) o = satisfactory (3)						
o = barely sufficient (4) - = unsatisfactory (5)						

Figure 3. Evaluation sheet for the product testing method

The processes of weighing pros and cons and evaluating them are reflected upon in the final phase. At the heart of this reflection stand questions about how such evaluations occur and how they are influenced by the individual decisions of the people conducting the test and/or writing the reports. This reflection focuses on the role of scientific information and its constant transformation and filtering in the process of evaluation, but also touches upon the reliability of information sources and the transformative process, which occurs whenever members of consumer testing agencies use, relate and weight information in the sense of filtered information as suggested by Eilks, Nielsen and Hofstein (2014).

The ESD-driven classroom example presented above has great potential for developing relevant science education. It allows student learning in the individual domain on how to deal with growing waste problems in the environment, including making personal consumer choices. In the societal dimension students learn that society has to make decisions about environmental protection and regulations on the use of different products. This includes responding critically to consumer reports in the media. In the vocational range students get an idea what professional product testers do and what contributions from science and technology are provided to their measures.

Several industry-based modules have been developed in Israel since the late 1990s.

Bromine from the Dead Sea - an example from Israel

These modules target students who choose to specialize in advanced-level chemistry studies. The lessons include the underlying chemistry topics and concepts related to the industrial processes, the related technological, societal, economic, and environmental issues, and their interrelationships. Figure 4 presents the cover pages of the corresponding units. Figure 5 shows an overview of the aspects involved in one of the examples called Bromine from the Dead Sea (Hofstein & Kesner, 2006).

Until 2003 teaching one of the case-studies was obligatory and accounted for roughly 20% of the total curriculum. This was an integral part of the final matriculation examination, a central national examination prescribed by the Israeli Ministry of Education. About 65,000 students (an average of 6,500 students every year), studied one of the test cases. This represented 100% of the students taking chemistry as a major during these years. Although the case-studies are not obligatory today, roughly 400 students every year study them as an elective module. The last unit, which was developed in 2007, focused on environmental issues such as water quality and global warming as the leading context for studying the relevant scientific concepts. The unit is an elective for chemistry majors. During 2008-2013 about 3500 students (about 500 students every year) studied the unit. This represents about 10% of all chemistry majors and the number is gradually growing.

In order to incorporate sustainability issues and competencies into the formal curriculum, the students are asked to address environmental dilemmas like producing bromine near the fragile Dead Sea ecosystem (Figure 5). They are also required to reflect upon the advantages and disadvantages of issues such as the location of an industrial plant, various industrial processes, different construction materials, and available

separation techniques. They are forced to think about the pros and cons of certain issues, to suggest solutions and to recommend a compromise solution based on scientific data. The rationale behind this pedagogy is that active participation leads to a better understanding of the issues at hand and also increases students' personal interest. Some of the activities are based on group work in order to encourage the students to conduct collaborative discussions, compare different solutions with their partners, and evaluate information.



Figure 4. Overview of the different case study materials

Development of several modules included guided activities in order to promote the meaningful inclusion of field trips during chemistry education. Excursions are known to be very important and motivating for students (Orion & Hofstein, 1994). However, this is true only if the field trip is set up properly, the necessary learning materials are provided and an appropriate pedagogical approach is employed. Orion and Hofstein suggested several guiding principles, which were adapted for this purpose:

- A pre-visit phase to equip the students with necessary background information,
- An educationally effective visit to maximize learning,
- A carefully planned and orchestrated actual

visit to the industrial plant,

- And a post-visit (summary) phase in which a discussion regarding the students' experiences was conducted in the classroom.

Orion and Hofstein (1994) found that in test cases strictly following the suggested instructional model, students demonstrated significant improvements in their knowledge and attitudes as compared to students in classes with a less- or non-structured approach. To make this model adequate for field trips to industrial sites and natural areas where an environmental conflict is taking place, we prepared a set of manuals for such visits. Teachers underwent professional development training, including gaining scientific and technological background knowledge about an industrial plant or an environmental issue. They also learned methods to help prepare their students for such visits. About 3500 students participate in the structured field trips every year.

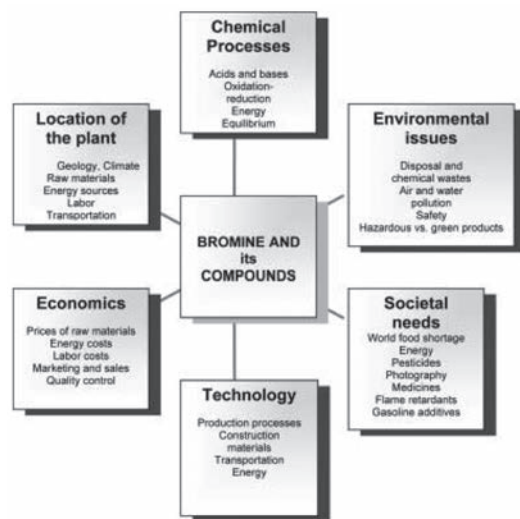


Figure 5. Overview of the case study on "Bromine and Its Compounds"

These ESD-driven classroom examples of industrial chemistry case studies have shown great potential for contributing to relevant science education. Students can learn in the individual domain how they should react to environmental challenges at the private and local levels, as well

as how they should behave as a consumer. In the societal dimension students learn how society makes decisions at the local and national level, how regulations and investments in industry come about, and how entrepreneurship and society interact. In the vocational range the students get an idea of which jobs are connected to the chemical industry and which chemistry-related businesses exist in the country.

Conclusions

Combining the ideas of relevant science education and ESD offers great opportunities for innovations in the chemistry curriculum towards Vision III scientific literacy. Especially SSI-based science education has strong potential for implementing ESD in chemistry teaching for more relevant science teaching and learning. The concepts discussed above for understanding the different dimensions of relevant science education, different visions of scientific literacy and the different modes of ESD-driven science education practices offer good tools for reflecting on science education curricula and teaching practices and also for guiding reform thereof.

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Learning about Sustainable Development in Socio-scientific Issues

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Abstract

This paper deals with the application of socio-scientific issues-based (SSI) science education in the secondary chemistry classroom. Issues of sustainable development are suggested to contextualize chemistry learning. If this is operated in an SSI approach controversial issues from the sustainability debate are used to motivate chemistry learning under thorough inclusion of a societal perspective. Examples will be presented from secondary chemistry teaching in Israel and Germany. The issue of alternative fuels will serve as example. The discussion will show that a combination of SSI science teaching with issues of sustainable development and Green Chemistry offers a fruitful approach to motivate chemistry learning and contribute the development of general educational skills.

Introduction

Sustainable development was defined as a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (UN, 1987). In the following years, sustainable development became a guiding principle of international policy. The idea of an Education for Sustainable Development (ESD) was suggested (UNCED, 1992). ESD is a skill-oriented educational paradigm aiming on the preparation of young people to become responsible future citizens (Burmeister, Rauch & Eilks, 2012; Stuckey, Hofstein, Mamlok-Naaman & Eilks, 2013)). For sustainable development of our present and future society decisions are to be made, e.g., on resources consumption, environmental protection, or new and alternative technologies. Many of these decisions are related to chemistry and chemical industry (Bradley, 2005).

Investment in chemistry curriculum development and teacher education is needed to develop general and domain-specific knowledge and skills in the learners that enable the students in the future to assess and decide about chemistry-based products, technologies and processes (Burmeister et al., 2012). All students need to develop

corresponding skills irrespective to whether they later will embark in a career in science and technology or not, because all of them will be asked to act as responsible citizens in the future and to contribute to societal decision making (Hofstein, Eilks & Bybee, 2011).

Burmeister et al. (2012) suggested four basic modes of how to integrate ESD with chemistry education. The modes range from (1) an application of Green Chemistry principles in school science practical work, via (2) using sustainability issues to contextualize chemistry content learning, towards (3) addressing technological and environmental challenges in socio-scientific issues-based science education, and finally (4) innovating school life along sustainability principles. Concerning the development of domain-specific educational skills for participation in societal debate and decision making about chemistry-related issues of sustainable development Burmeister et al. (2012) suggested socio-scientific issues-based (SSI) science education as one of the most promising strategy.

Socio-scientific issues of sustainable development and chemistry teaching

Stolz, Marks, Witteck and Eilks (2013) suggest-

ed quality criteria for selecting and reflecting societal contexts on their potential to act as socio-scientific issues in SSI science teaching:

- **Authenticity:** The topic is authentic, when it is currently being discussed by society. For proof, common media can be checked for presence of the topic, e.g., in newspapers, magazines, TV, or advertising.

- **Relevance:** The topic is relevant, if respective decisions will affect the current or future lives of the students. Scenarios are reflected to see which impact potential decisions will have, e.g., on behavioural choices, consumer behaviour, or availability of products.

- **Evaluation is undetermined in a socio-scientific respect:** The socio-scientific issue allows for different points-of-view. Media can be analyzed whether controversial viewpoints are represented, e.g., by interest groups, the media, politicians, or scientists.

- **Allows for open discussions:** The topic must allow for being discussed in an open forum. Thought experiments test arguments to make sure that no individuals, religious or ethnic groups would feel themselves to be insulted or pushed to the fringes of society by their use.

- **Deals with an issue based on science and technology:** This topic concerns itself with a techno-scientific query. Discourse in the media is analyzed. The question is raised, whether scientific facts and concepts are addressed and either explicitly or implicitly used for argumentation.

Many chemistry-related issues of sustainable development are in alignment with the above criteria. For example, the use of alternative fuels is discussed in mass media. Regulations on their use will potentially have impact on the students' consumer choices. The use of alternative fuels is still controversial, and this issue raises questions regarding chemistry and technology, as well as encouraging public debates. The following will serve as an example about the enactment of SSI in the chemistry classroom.

An example of issues of sustainable development in the SSI chemistry classroom:

Teaching and learning on traditional and alternative fuels

In recent years, in Israel a group of teachers developed a lesson plan which was called "Can used oil be the next generation fuel?" (Ezra, Skolnick and Aghbaryia, 2012). This lesson plan focuses students learning about traditional and alternative sources of fuels. The students should learn about the advantages and disadvantages of each of different suggested technologies: fuels from crude oil, recycling of used oils, or producing biodiesel from vegetable oil.

The lesson plan uses a structure coming from the socio-scientific issue, via learning about the content behind the issue, towards questions of evaluation and reflecting the issue from different perspectives and in the foreground of the societal discourse. This structure is parallel to those suggested in the curriculum models by Marks and Eilks (2009) or Holbrook and Rannikmae (2010) for SSI science education.

The lesson plan starts with students being exposed to information about the world's energy crisis and its consequences. This information is discussed to activate prior knowledge and create questions. The idea that teachers should convey to their students is that the crisis is a worldwide problem and is not only another scenario for the science classroom. It is also made clear that there are several proposed solutions to this crisis, but often these solutions introduce new problems.

In order to make any decision regarding the various fuels students undertake different activities to investigate and compare the fuel types. One activity is that the students are requested to inquire into the chemistry of the use of different fuel types, one of which is biodiesel. Comparative activities require students to select criteria such as enthalpy of combustion values or the release of emissions. The teacher introduces the student to an experiment that compares the energy released by the combustion of different fuel types. By measuring the mass of the fuel needed

to increase the temperature of a certain volume of water by 30 degrees Celsius, students can compare the caloric value of different fuels. They also can investigate the level of pollutants emitted from the burning fuels with a special board called the "Ringelmann Scale." The Ringelmann scale determines the concentration of soot particles accompanying the flame.

Following the comparison of chemical behaviour students are requested to decide: Which is the best fuel? Before making a final decision there is an attempt to involve students emotionally and involving an ethical perspective by creating a conflict regarding the use of biodiesel. This activity is based on viewing pictures that highlight the use of crops for fuels instead of using them as a food source in our world's growing population. Students' decisions should be based on arguments, but their decision first needs an agreement within the group what they suggest to be the meaning of "the best" fuel. This discussion leads to understanding that a thorough comparison requires more criteria behind chemical behaviour. These criteria need to include price, environmental behaviour, production methods, or societal impact. An open discussion about which technology has the most promising potential for sustainable development closes the lesson plan. Within this lesson plan, the students learn about an authentic sustainability issue and the complexity of its solution. On the one hand, they learn that there is no "best fuel" nor any "best solution" to many sustainability problems. On the other hand, they learn that making use of used oil or bio-fuels is not "the ideal solution", too. Both ways can offer a contribution to environment protection because less waste is produced and fossil resources are also saved. However, the students also learn how complex such evaluations are and how many dimensions need to be taken into consideration if an overall decision is to be requested.

In 2002, Eilks suggested a lesson plan on biodiesel usage; a couple of years later a quite similar lesson plan was published concerning the soci-

etal debate about the use of bio-ethanol (Feierabend & Eilks, 2011). Both lesson plans follow the curriculum model suggested by Marks and Eilks (2009) and include some innovative pedagogy. They start from authentic media from the public debate. In the case of biodiesel advertisements and brochures from pressure groups are used to open the context and to provoke questions. In the bio-ethanol example articles from news magazines are analysed on the concurrency of food and fuel production. In both cases, questions are derived from the material. Student questions regularly concern the science behind the issue. Starting from the public media consequently other questions are regularly also set up. The questions encompass aspects of consumer behaviour, but also on implications of the new technology. Implications are put into question stemming from the different fields of economy, ecology and society – the three most prominent dimension in current models of sustainability (Burmeister et al., 2012).

After a start from authentic media, the applied curriculum model suggests a phase of clarifying the basic chemistry behind the issues. This is the chemistry of fat and trans-esterification or of fermentation and alcohols, respectively. Learning the science background is done in a combination of theoretical learning and practical work. Similar experiments are done as suggested in the previous example from Israel. Additionally, bio-fuels are produced by trans-esterification of rape seed oil and distillation from fermented grapes, respectively.

Reflecting the chemistry content learning makes clear that chemistry only can help understanding the technological background behind the issue. However, balanced evaluation and decision-making need to also include ecological, economic, and societal aspects. For learning about how society is handling socio-scientific issues the curriculum model applied suggests the mimicking of an authentic societal practice of communication and decision making (Marks & Eilks, 2009; Eilks et al., 2014). Consequently, in

both lesson plans role play activities were implemented. In the biodiesel example the students mimic a public panel discussion. Discussants are students representing stakeholders from crude oil industry research, a traditional gasoline company, a pressure group for biodiesel promotion, and an environmental protection agency. On bioethanol a role play is operated in the means of a business game. In this case the scenario is that a parliament's committee has to suggest a decision of making 10% bioethanol in all the gasoline compulsory. This was an authentic scenario since Germany was discussing exactly such a law during those days the lesson plan was developed. In the business game a fictive commission conduct a hearing with different student groups, representing chemists, engineers, environmental protection groups, car manufacturers, etc.

In both cases of role playing, intense debate regularly emerges among the students. The students experience which perspectives contribute to respective decisions. They face the situation that is not only chemistry, science and technology providing relevant arguments in the chemistry classroom; arguments stemming from economy, ethics, ecology and many other fields are needed for a balanced view. The students also learn which arguments are selected by different societal groups and how they are put into the debate. The learners even see that science-related arguments are mainly not introduced by scientists. Representatives of industry and pressure groups purposely select from the available scientific information and use them in a way that it supports their interests. The representatives take their choice from the available arguments and transform them as they like. Hofstein et al. (2011) named this the idea of filtered information. All these observations are reflected in the final part of the lesson plan to contribute to students' skills of understanding and critical reaction to public debate about sustainability-related socio-scientific questions.

Conclusions

The media deals constantly with sustainable is-

ues (Mandler, Mamlok-Naaman, Blonder, Yayon & Hofstein, 2012). A scientifically literate person is often appalled by the way scientific facts and theories are misstated (in the means of the idea of filtered information) and how the roles of science and technology in both causing and curing these problems are misunderstood. Therefore chemistry education needs to prepare students to deal informed with these issues as chemistry-literate citizens in a world in which they are able to confront new problems intelligently (Eilks et al., 2014).

Contextualizing chemistry by environmental issues suggests an effective method of motivating the students to learn chemistry (Mandler et al., 2012). Adding sustainability and environmental contexts can increase students' perceptions of how relevant chemistry is to real-life problems and this will raise motivation (Eilks, 2002). Motivating the students to study science, while for example providing a good understanding of chemical concepts, was ranked among the most important concerns in chemistry education (Zoller and Pushkin, 2007).

The inclusion of sustainability and environmental contexts into chemistry education can have a significant impact on students' awareness of how chemistry is connected to the real world (Eilks, 2002). Students become more aware of the relationships between chemistry and the society in which they live (Marks & Eilks, 2009). Basic science knowledge is crucial for promoting sustainable development and improving the capacity of the people to address environmental and developmental issues, and thus the latter needs to be incorporated as an essential part of chemistry learning. Integrating chemistry learning with sustainability and environmental contexts is very much in line with the idea of ESD. This represents the context-based mode of integrating ESD with chemistry learning as suggested by Burmeister et al. (2012).

However, learning chemistry focusing sustainability in a SSI mode should have a broader impact. Learning chemistry can directly help cit-

izens to better react to sustainability and environmental issues by providing data and theories that define the problem, assess its seriousness, and explain its causes. The NEETF environmental literacy report recommends that people should receive concrete suggestions on how to change their behavior, with an emphasis on how they can join others who are doing the same thing (Coyle, 2005). The report notes a positive correlation between environmental knowledge and environmental behaviors. The more you know, the more likely you are to act to take positive steps to improve the environment (Coyle, 2005).

Acting for a sustainable development also encompasses participation in societal discourse and decision making (De Haan, 2006). The discussion in this paper makes clear that raising learning success in pure chemistry knowledge is not sufficient to fully understand or to participate in societal debate on socio-scientific issues concerning questions of chemistry and chemical technology (Burmeister et al., 2012). A broad skill-set is needed to become able to act responsibly in the societal context (De Haan, 2006). Communication and decision making skills need to be developed as well as skills in analyzing how science and chemistry related arguments are used in society (Eilks et al. 2014) – and chemistry education should contribute to it. Integrating chemistry learning with issues of sustainable development offers great chances for creating learning environments that contribute general skill development beyond pure chemistry (Eilks, 2002; Marks & Eilks, 2010). If operated in an SSI approach there is chance given, that chemistry learning thoroughly starts contributing development of those skills important for shaping the society in a sustainable fashion (Burmeister et al., 2012). The examples presented in this chapter show that corresponding lessons plans have great potential to both motivation and promoting chemistry learning on the one side as well as general educational skill development on the other.

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Introducing Responsible Research and Innovation (RRI) into the Secondary School Chemistry Classroom: The Irresistible Project

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Abstract:

Responsible research and innovation (RRI) has become a core concept in some of the Horizon 2020 programs. In this chapter the concept of RRI is discussed according to the interpretation used within an EU-sponsored project, Irresistible. In the chapter we present several ways in which RRI can be introduced in secondary science education, coupled with contemporary research taking place in universities, as well as with recent innovations coming from industry. The discussed modules were designed in groups in which teachers work together with science researchers, educational researchers and people from science centers. The chapter focuses on the Israeli module that deals with the leading question: "Under what conditions would we agree to have perovskite-based photovoltaic cells installed on the windows of our school?" An innovative aspect of the pedagogical approach is the development of student-designed exhibits in which both the science content as well as the relevant RRI concepts are demonstrated for the general public. These exhibits have been very successful as a learning tool.

Key words: Secondary school education, Science education, Chemistry education, Formal learning, Informal learning, Student-designed exhibits, Responsible Research and Innovation, RRI, Contemporary science, Cutting edge research

Introduction

Responsible Research and Innovation (RRI) stands at the centre of several EU projects and represents a contemporary view of the connection between science and society. Previous 'techno-disasters' together with many facets of the current financial crisis have resulted in a loss of public trust in science and scientists across the

world. The goal of RRI is to create a shared understanding of the appropriate behaviours of the European Commission, governments, business and NGOs (non-governmental organizations) which are central to building trust and confidence of the public and other stakeholders in safe and effective systems, process and products of innovation (Sutcliffe, 2011). The Irresistible project focuses on the design of science education activ-

ities that foster the involvement of students and the public in the process of responsible research and innovation. In the Irresistible activities, both formal and informal learning environments play an important role. The project raises awareness about RRI in two ways:

1) Increasing content knowledge about research by bringing topics of cutting-edge research into the program, and

2) Fostering a discussion among the students regarding RRI issues about the topics that are introduced.

In this chapter we describe the concept "Responsible Research and Innovation" (RRI), as well as the way it is introduced to students in secondary science education.

What is "Responsible Research and Innovation"?

Throughout the world, ideas about the interaction between science, innovation and society have become a subject of discussion. The UN, for example, has formulated millennium goals (The eight Millennium Development Goals (MDGs), 2015) for science. The OPCW has formulated the Hague Ethical guidelines (2015). Within the industrial society the idea of Responsible Care (2016) was written; and within the EU, this discussion has been going on for a while resulting in several framework programs.

Within the EU, the Framework programs about science and society have shifted in title from 'Science and Society' to 'Science in Society', indicating the change in perception within the EU about the role of science (Hoven, 2013). The concepts of Responsible Research and Innovation have become more and more important. In Hillary Sutcliffe's report (Sutcliffe, 2011) she identifies six key dimensions in RRI.

In a later leaflet published by the EU in 2012 (EU, 2012) six key issues are identified: 1. Engagement; 2. Open Access; 3. Ethics; 4. Science Education; 5. Gender Equality; and 6. Governance. The six dimensions and their explanations

are presented in Table 1. Several other definitions for RRI were provided and further contributed to the RRI concept.

Van Hoven (van Hoven, 2013) indicates:

"RRI refers to ways of proceeding in Research and Innovation that allow those who initiate and are involved in these processes at an early stage (A) to obtain relevant knowledge on the consequences of the outcomes of their actions and on the range of options open to them and (B) to effectively evaluate both outcomes and options in terms of ethical values (including, but not limited to well-being, justice, equality, privacy, autonomy, safety, security, sustainability, accountability, democracy and efficiency) and (C) to use these considerations (under A and B) as functional requirements for design and development of new research, products and services."

Schomberg (von Schomberg, 2013) defines RRI as follows:

"Responsible Research and Innovation is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society)."

Both Schomberg and van Hoven focus on the interaction between society, on one hand, and and research and innovation, on the other. They demonstrate the importance of this interaction in order for research and innovations to succeed in society. A common example is genetically modified food, which has not been accepted in Europe. Especially the steps formulated by van Hoven are not common as yet even though governments have started to formulate policies on this subject. In the Netherlands, for example, a new report was published indicating the view of the Dutch government on the future development of policies regarding scientific research, which are solidly based on these RRI concepts (Wetenschapsvisie 2025, 2014).

Within the Irresistible project we decided to use the six key issues (presented in Table 1) as a starting point in the design of the activities within the project. They provide a more concrete set of issues that can be incorporated within educational activities. The underlining idea, that both research and innovation should be closely linked with society and with societal needs is the background of the use of these six dimensions. Using the six key issues gave the project a solid base to discuss how the cutting-edge research could be introduced to the students. In order to be able to work according the six RRI dimensions, we developed a more descriptive explanation of them, as presented in Table 1.

1. Engagement
The first key to RRI is the engagement of all societal actors - researchers, industry, policymakers and civil society – and their joint participation in the research and innovation process, in accordance with the value of inclusiveness, as reflected in the Charter of Fundamental Rights of the European Union. A sound framework for excellence in research and innovation entails that the societal challenges are framed on the basis of widely representative social, economic and ethical concerns and common principles. Moreover, mutual learning and agreed practices are needed to develop joint solutions to societal problems and opportunities, and to pre-empt possible public value failures of future innovation.
2. Gender Equality
Engagement means that all actors – including women and men – are on board. The under-representation of women must be addressed. Research institutions, in particular their human resources management, need to be modernized. The gender dimension must be integrated in research and innovation content.
3. Science Education
Europe must not only increase its number of researchers, it also needs to enhance the current education process to better equip future researchers and other societal actors with the necessary knowledge and tools to fully participate and take responsibility in the research and innovation process. There is an urgent need to boost the interest of children and youth in maths, science and technology, so they can become the researchers of tomorrow, and contribute to a science-literate society. Creative thinking calls for science education as a means to make change happen.
4. Open Access
In order to be responsible, research and innovation must be both transparent and accessible. This means giving free online access to the results of publicly-funded research (publications and data). This will boost innovation and further increase the use of scientific results by all societal actors.
5. Ethics
European society is based on shared values. In order to adequately respond to societal challenges, research and innovation must respect fundamental rights and the highest ethical standards. Beyond the mandatory legal aspects, this aims to ensure increased

Table 1. The 6 Dimensions of RRI used in the Irresistible project

In order to get a clear idea about the use of these six dimensions of RRI and to share the same understanding within the project's partners, a workshop was organized by the Weizmann's partners, in which the coordinators in each participating country participated. During that workshop, two

case studies were discussed in which the six dimensions could be applied.

The first case study that was discussed was the use of asbestos. The group discussed whether applying of RRI policies could have changed the use of asbestos in society and prevent the catastrophe caused by its use. Main question to be answered during the workshop was how the problems with asbestos could have been avoided, using RRI-based policies. For the second case study, nanosocks were introduced. (see Figure 1.)



Figure 1. Nanosocks

Nanosocks (2016) contain nano silver particles that inhibit bacterial growth and thus prevent smelly socks. This contemporary innovation was used for a discussion about the six dimensions of RRI and the way they should be applied to nanosocks. Through this discussion, participants developed an idea about the way the six dimensions could be applied to an innovation like nanosocks. This experience was taken by the participants to be used during the development of educational material.

The Development of the Educational Material

Within the project, a Community of Learners (CoL) was formed in each country as the group to develop its educational material ((Loucks-Horsley, Stiles, Mundry, Love, & Hewson, 2010). Both in the Netherlands in the development of 'Nieuwe Scheikunde' (Apotheker, 2008) as well

In the Irresistible project, each CoL included experts from science research, educational research, science centres, teachers, and (when possible) a representative from industry. Together the CoL members worked on the development of the new educational material. The pedagogy of inquiry was chosen to lead the new teaching and learning materials. We chose to use the 5E method developed by Roger Bybee (Bybee, Taylor, Gardner, Van Scotter, Carlson, Westbrook, & Landes, 2006) as a framework for the modules to be developed. The Irresistible group decided to expand the 5E model with a step called Exchange, in which the students exchange their results and build an exhibition. In Table 3, the resulting 6E model is represented.

Phase	Description	Techniques used
Engage	Students are motivated to engage in the subject of the module. Both formal and informal learning activities are planned.	TV broadcast, visit to science centre, video introduction, apps, lecture by researcher. Students may gather information using smartphones to make videos, photos or other data that can be shared via social media (e.g., a Facebook group).
Explore	Students formulate questions plan explorations, and implement their plans.	A Web platform is used for gathering data and for comparing and sharing results.
Explain	Students gain knowledge through data collection and scaffolding. The main concepts are explained.	The teachers and the students will scaffold the content knowledge on the web platform.
Elaborate	The attention shifts to elaborating on the concepts by asking RRI-questions. Students confront researchers with challenges to be answered by the scientists.	Using the web platform, students match questions and answers by scientists.
Exchange	Students design and construct an exhibit, to be displayed in the science centre in the partners' local group. Posters or other presentation modes may also be used.	Contest for best exhibits, which will participate in an exhibit on a European scale, hosted by one of the partners.
Evaluate	Students are tested on their content and RRI-related knowledge. The students themselves determine by an interview/ discussion with the researchers what they learned from the project.	Online tests and surveys can be used for testing and for discussion with the researchers.

Table 3. The 6E Model for Inquiry-Based Learning Used in the Irresistible Project Results

Thirteen different modules dealing with variety of cutting-edge science topics were developed by the Irresistible partners. Each partner chose a research topic currently being investigated in their university and cooperated with the researcher to obtain contemporary scientific information. Table 4 presents the topics of the modules developed by each partner.

Country	Title of the Module	Cutting-Edge Research Topic
Finland	Atmosphere and Climate change	Atmosphere and Climate change
Germany	Oceanography and climate change	Offshore wind energy
	Plastic, Bane of the Oceans	Plastic waste in oceans
Greece	Nanoscience applications	Several nano-applications like the lotus effect
Israel	The RRI of Perovskite-based photovoltaic cells	Perovskite solar cells
Italy (Bologna)	Nanotechnology for information by exploiting light/ matter interaction	Luminescent nanosensors
Italy (Palermo)	Energy sources	Graetzel cells
Netherlands	Carbohydrates in breast milk	Specific oligo-saccharides
Poland	The catalytic properties of nanomaterials	Role of nano particles as catalyst
Portugal	Geo-engineering and climate control	Geo-engineering
	Evaluating earth health through polar regions	Polar ecosystems
Romania	Solar energy and specific nanomaterial	Graetzel cells
Turkey	Nanotechnology applications in health sciences	Nanomaterials used in health issues

Table 4. Produced modules, with science content.

All the modules included the 6E framework. The teachers in each CoL tried out their module in their own classrooms. The modules have been adapted using teachers' experiences in the classroom. A further improvement of the module was conducted by international exchange of the modules between the Irresistible partners. Each module was tested in a different country and the

feedback obtained was used to improve it. The modules are available through the Irresistible (2016) website.

Implementation of RRI

The implementation of RRI in the modules has been done in different ways. In the modules of Israel, Turkey and Germany the students are given a specific role. Incorporated in the role-play are the different RRI aspects. In the Turkish module the students are given the role of an advisor. A hospital is asking them whether or not the hospital should introduce towels sheets and other products made of textile treated with nano silver particles that have antibacterial properties. They then investigate the properties of cotton treated with silver nanoparticles and finally, by discussing the consequences of washing textile-containing silver nanoparticles, they highlight the key aspects of RRI and come up with a recommendation.

In the German module, a game has been developed in which the students play different roles and in this way learn about offshore wind energy. Since the Fujiyama disasters in Japan, Germany decided to invest heavily in wind energy.

The students' main question in the Israeli module is "Under what conditions, if any, would we agree to have perovskite-based photovoltaic cells installed on the windows of our school?" The module includes the following components: (1) a pre-visit RRI unit for the students, given in their classroom before the visit, (2) a visit to the Weizmann Institute's outdoor science museum (The Garden of Science) on the topic of alternative energy (Figure 2), (3) a high-quality "special news broadcast" which frames the guiding question for the students, (4) background articles for the students, (5) a lecture on alternative energy and photovoltaic cells, (6) a student experiment on photovoltaic cells and (Figure 3), (7) an activity to help students design exhibits, based on the guiding question, (8) a discussion with Weizmann Institute graduate students about

their research, from an RRI perspective, and (8) a post-visit session on building the exhibits, back in the classroom, leading to a presentation of the exhibits to other students.

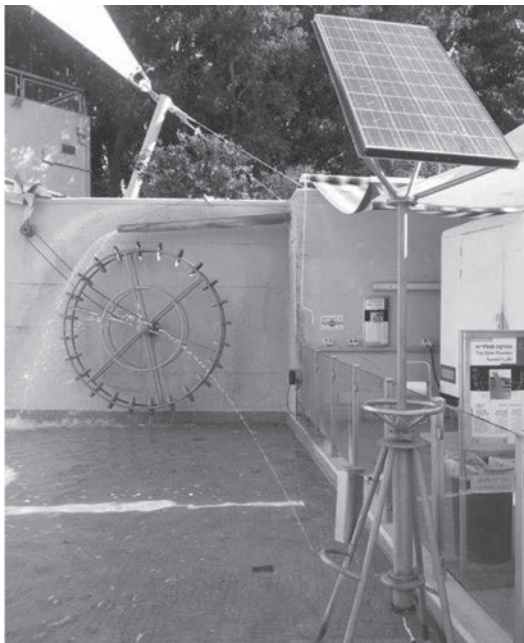


Figure 2: One of the exhibits in the Clore Garden of Science, demonstrating the working principle of solar panels.

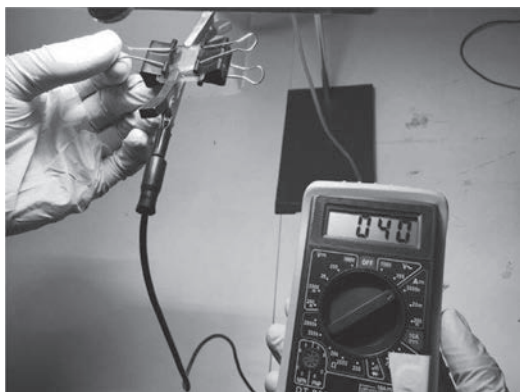


Figure 3: A solar cell built during the students' visit in the Weizmann Institute of Science, to deepen their knowledge of the working principle of solar cells.

The six areas of RRI are addressed by the module in a number of ways. First, before the students arrive at the Weizmann Institute, they receive a 3-hour lesson on RRI (Blonder, Zemler,

& Rosenfeld 2016) which is based on the history of the use of lead in different industries. The students are challenged to think of ways in which the use of lead in these industries could have been prevented and they are guided to learn about the six keys of RRI. Second, the students are engaged in thinking about RRI during their visit to the Weizmann Institute, in terms of the module's guiding question regarding the use of perovskite-based photovoltaic cells. Third, the students design an exhibition that includes RRI dimensions of the perovskite-based photovoltaic cells innovation. Finally, toward the end of their visit, the students meet Weizmann Institute graduate students, who describe their research and invite students to ask them questions regarding this research as it relates to RRI.

In other modules, the RRI dimensions were introduced during the 'Elaborate' step of the 6E framework as a separate part of the module. Students were then asked to apply the RRI dimensions to the science content they studied in the first part of the module, and to present their findings in various ways.



Figure 4. Students debating about propositions, in the Netherlands.

In some cases a debate was organized around specific propositions such as, "A company has the right to market their products all over the world," taken from the module about milk formula, as shown in Figure 4.

In all cases, the students were asked to design and construct an exhibit demonstrating the dimensions of RRI and focusing on the the relevant science content.. These exhibits were taken

to the local science centre involved in the project and displayed there. Students were guided in their exhibit-designing efforts by the science centre staff.

In Germany, a system for the exhibits was developed using a cupboard from 'Ikea' (Figure 5). The cupboard was designed by the students to illustrate the issues involved. In this case, the module is about the differences between human milk and cow milk.



Figure 5. Use of an Ikea cupboard as the base for an exhibit (The Netherlands exhibition).



Figure 6. Use of QR codes to create interactive exhibits (from the Israeli exhibition).

In other cases, interactive exhibitions were created by applying technologies such as QR codes and on-line quizzes, as demonstrated in Figure 6 by one of the exhibitions that was developed in Israel. Students are very creative in designing exhibits. Through careful guidance by the experts from the various science centres, exhibitions are made that can actually be used in these science centres.

Conclusions and Recommendations:

Looking at the modules and more specifically at the exhibits that have been produced by the students, it becomes clear that the Irresistible modules are able to introduce cutting-edge science research into the secondary school classroom. In most cases, this approach fits in with the curriculum in a country, and in other cases the material is considered extra-curricular enrichment.

What also becomes clear is that the students are very able to link the RRI dimensions to the science they have been studying. In Israel RRI has become more or less a verb: 'Let's do RRI on this issue' (Blonder, Zemler, & Rosenfeld, 2016). The exhibits are an important factor in the modules in bringing together the science and RRI. Designing the exhibits forces the students to think about the issues and come up with ways to demonstrate to society the RRI dimensions of the research and/ or innovation.

In most modules, all six dimensions were addressed. During a presentation of the modules in a meeting of the project in Bologna, it became clear that the gender dimension as well as the science education dimension were not always easy to implement in the modules. These two dimensions were found to have high societal importance and therefore the awareness of the students to their importance is essential. However, it is not trivial to use them as a lens to examine a scientific research or an innovational development.

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Promoting Education for Sustainability for All Learners by Non-Formal Chemistry Laboratories¹

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Abstract

Diversity and heterogeneity are getting more and more noticeable in schools in general and science classes in particular. This is the case for many countries around the world, among them Germany. Thus, innovations in science teaching are needed. This holds true for schools and also non-formal learning environments. A special type of non-formal learning environments for school students, in German called “Schülerlabor”, was implemented in many German universities and research centers in recent years. The justification was originally given by aspects of motivation. The aim was to overcome a shortage in young people embarking into academic careers in science and engineering. This is why Schülerlabor settings were originally aiming at more mature and higher achieving students. This chapter reports on a different approach. Starting from the challenges of diversity and heterogeneity, the project “Chemistry, Environment, Sustainability: Non-formal Learning Environments for All Students” focuses on science learning for all students via Schülerlabor environments. A special model for differentiated teaching and learning in Schülerlabors is presented. This model takes into account students’ diversity and heterogeneity in their personal interests, cognitive skills, problem-solving capabilities, and linguistic skills. The project also focuses on developing creative approaches to chemistry experiments for motivating especially those students who are less skillful and less motivated in learning science.

Introduction

Traditionally, most teachers prepare their chemistry classes with a view on their group of students. Often, they are talking about the group of students having one material prepared to fit all the students in the same time. However, students in one class are never the same and heterogeneity started growing in many countries in recent years, e.g., in Germany. The students do not bring with them the same prior knowledge and experiences, do not have anymore the same cultural or socio-economic background, and do not possess the same cognitive, physical and linguistic skills. Thus, the students bring different requirements with them into class that can be identified by the dimensions named in the Diversity Wheel (Figure 1).

In the literature there are different ways described of how to deal with diversity and heterogeneity in science classes. An overview is given

in Markic and Abels (2016) where the different dimensions of diversity are discussed and examples are provided for science learning under the idea of inclusive education.



Figure 1. Diversity Wheel (http://web.jhu.edu/dlc/resources/diversity_wheel/)

In 2012 the OECD described the growing importance of informal and non-formal education to support formal learning in schools. They defined informal learning as out-of-school learning without structure and curriculum (e.g., individual visits to museum, zoos, or science exhibits, viewing science-related programs on TV and videos, reading articles and books in printed or digital form and some more). Also non-formal learning occurs outside traditional school environments. However, non-formal learning tends to have a specific structure and is often connected to various types of prescribed programs or curricula (e.g., Coll, Gilbert, Pilot, & Streller, 2012; Stocklmeyer, Rennie, & Gilbert, 2010). Reflecting two examples from Ireland and Germany Garner, Hayes, and Eilks (2014) recently discussed the potential which non-formal educational initiatives have with respect to curriculum development and innovation in science education. They point out that the greater freedom and flexibility available in non-formal education provides rich opportunities for learning, but also for developing and testing of new teaching and learning scenarios, e.g., new experiments, pedagogies, and media. The greater freedom and flexibility of non-formal learning environments is suggested to be of high potential for adaptable and differentiating learning environments to meet the challenges of growing diversity and heterogeneity.

The Schülerlabor as a place for non-formal learning and innovation

A special type of non-formal learning laboratory environments emerged in recent years to promote primary and secondary science education in Germany, the so-called Schülerlabor (Haupt et al., 2013). The term Schülerlabor (SL) can be translated as student laboratory (Schülerlabors is a plural form - SLs). In German language the word 'Schüler' refers only school students and not to university students, as it is the case in English. 'Labor' is the German term for laboratory. Today, more than 300 SLs exist all over Ger-

many. Most of them are connected to universities, but also some research institutes or industry plants offer SLs (Hempelmann, 2014).

Starting from the shortage of young people embarking in science and engineering professions, the original idea of founding SLs was to motivate more school students to engage in academic careers in science and engineering. This is why most SLs in the beginning were focusing on older and higher achieving school students. Starting from here, the idea of SLs developed into a broad nation-wide movement. The original idea changed and the intentions moved toward supporting science learning on a general level. The SLs started offering out-of-school learning experiences for students of all schooling levels and providing them chances to do practical work beyond the limited possibilities in most of the schools, limited by a lack of equipment, time, or the overall quality of the school science resources. The rationale behind the SLs today is to promote science learning at all levels and to improve students' engagement in science and engineering studies in general (Haupt et al., 2013). Regularly, SL-visits are half- or full-day excursions of whole classes to well-equipped laboratories in universities, research institutes, or industry plants, where practical work takes place. In most cases, SL-visits are compulsory learning events for all students, since the whole class with their teacher does the excursion as an official school event. Activities in the SLs generally follow a prescribed structure and the visits are not always connected to the school curriculum. In many universities SLs are also used as part of pre-service teacher education by asking student teachers to supervise school classes in the SL as part of their university teacher training (Hempelmann, 2014; Haupt et al., 2013).

Up till now, research on the effects of the SLs is limited. Initial studies indicate that SL-visits have potential for achieving positive short- and medium-term effects with regard to levels of situational interest and motivation (Guderian & Priemer, 2008). Itzek-Greulich et al. (2014) dem-

onstrated that SLs can also lead to improvements in cognitive achievement. Zehren, Neber and Hempelmann (2013) concluded in their study that repeated visits to the SL, especially when adapted to formal learning in school, can also lead to long-term effects in terms of motivation and achievement.

Just recently, Garner, Siol, Huwer, Hempelmann and Eilks (2014) and Garner, Siol, and Eilks (2015) reported a SL-project which is focusing on the implementation of current topics from chemistry and chemical technology into science education under consideration of contexts from and issues of sustainable development. Furthermore, this project documented promising indications of a rise in student motivation. The project also generated useful contributions to curriculum innovation and teachers' continuous professional development. Students and teachers learned about current developments in sustainable chemistry, e.g., ideas of green chemistry. Teachers had a chance to learn about innovative pedagogies in science teaching and experienced new experiments. Thus, the teachers were able to get new ideas about teaching, new issues and in the same time experienced how their students reacted to them. SLs also offer situations where teachers can support their students individually thereby further developing their personal views of themselves and of their students. Teachers improved both their content knowledge (CK) and pedagogical content knowledge (PCK), and learned how new experiments and experimental techniques can be effectively carried out in educational settings.

Chemistry learning and education for sustainability in the Schülerlabor for all students

A cross-country initiative of non-formal student laboratories for all students

from the literature it is known that environmental attitudes and acceptance of sustainability thinking tend to be quite developed among more mature, higher-achieving students, especially those

with advanced educational backgrounds (e.g., based on a high socio-economic status and academic background of their parents) (Michelsen, Grunenberg, & Rode, 2012). Michelsen et al. (2012) also showed that the opposite is the case for many students with less-advanced educational biographies. These learners come from an environment characterized by a low socio-economic status often connected to a migration background of either the students or their parents, and sometimes combined with low linguistic skills. Regularly, low educational achievement in the sciences and less developed attitudes towards environmental stewardship including knowledge and skills in questions of sustainability have been found in this group of students (Michelsen et al., 2012).

Education for sustainability among students with less advanced educational biographies is a challenge for science education since these students often also have problems with general school achievement in many cases (Michelsen et al., 2012). To address this challenge, the project "Chemistry, Environment, Sustainability: Non-formal Learning Environments for All Students" (Affeldt, Siol, Markic, & Eilks, 2015) offers SL environments to all students, either with a more advanced educational background or with a disadvantaged educational biography, the chance of developing their knowledge and skills concerning sustainability issues in chemistry-related contexts. The project started from prior experiences in a similar project described in Garner et al. (2015) but taking into consideration more thoroughly the existing and growing diversity and heterogeneity in chemistry classes. The project intends to extend the potential of SLs towards science education for all students in the field of education for sustainability (Affeldt et al., 2015).

In the project by Affeldt et al. (2015) teaching and learning environments for lower secondary school science and chemistry classes as well as learning groups from other non-formal education providers, such as tutoring clubs, are developed. The project uses university laboratory visits as

the central pivot points. It employs the cooperation of four SLs located at four different German universities across the country, namely the Universities of Bremen, Erlangen-Nuremberg, of the Saarland at Saarbrücken, and the University of Education in Karlsruhe. Thus, four different federal states in Germany are working in this project.

All the project partners maintain well-established SLs and drive in-service chemistry teacher education centers for dissemination of the project outcomes. The partner at the Institute for Science Education of the University of Bremen is developing and piloting the learning environments. In the next step, these are transferred to and adopted by all of the other partners. The aim is to have each partner generate a minimum of 1500 students who have visited the different learning environments from each of the four SLs within a period of three years.

With regard to the organization of the non-formal SL visit, the learning experience is meant to be prepared in school by teachers before their classes visit the university laboratory environment. All of the laboratory instructions and supplementary materials, e.g., information for how to behave at the laboratory, are provided to the teacher by the SL staff before the visit. A manual explaining the background and the range of possibilities for the SL-visit is given to the teacher as well. It contains copies of the laboratory instructions and suggestions for further reading. This enables the teacher to acquire an overview of the topic and to prepare the students for the activities to be performed in the SL. The SL-visits take generally three hours. If the teachers want to extend the time, additional activities are provided. All topics (Table 1) for the different SL-modules have been chosen to meet the essential competencies and contents addressed by the aspect of sustainability. The target groups are secondary school science and chemistry classes in grades 5–10 (age range 10–16).

Grade	Module	Aspect of Sustainability
5/6	Discovering old crops for chemical and pharmaceutical industries	Stewardship of resources and the use of renewable raw materials
5/6	Exploring and improving water quality	Purification and efficient use of limited resources
7/8	Protecting and preserving metallic objects	The reduced need to continually use of natural resources
7/8	The contribution of chemistry to sustainable mobility	Renewable energy sources to protect resources and limit climate change; innovative materials for lightweight engineering
9/10	Energy storage for energy change	Sustainable energy supply, new technologies for energy storage, realizing greater energy efficiency
9/10	Bioplastics for a more sustainable future	The properties, synthesis, application, recycling and of different bioplastics

Table 1. Overview of the differentiated non-formal learning environments.

Each of the six learning environments offers a set of roughly 20 experiments of which teachers can select some. The selection depends on the time the students are staying in the lab, the topic that teacher is working in the moment and also the abilities that teachers sees for his/hers students. Such intense learning experience in school is generally not possible because of issues of time for preparation, equipment, and infrastructure. As presented in Table 1, all chemistry and sustainability learning aspects have been embedded into contexts taken from everyday life issues, the environment or technology. The focal points of the various modules cover different topics from chemistry curriculum like the properties of substances, various separation methods, electrochemistry, organic chemistry and sustainable technologies. Each module also includes a specific aspect of sustainability. The topics include water quality and water treatment, protecting and preserving objects, modern technologies in the context of sustainable mobility, and the sustainable synthesis of modern materials. Within the SL environments learning for sustainability is related to chemistry-specific contents and contexts, so that students can understand and participate in corresponding socio-scientific discussions. This also should allow them to make educated choices regarding whether professions in science and technology make sense for their future careers.

A model for differentiated learning in the Schülerlabor

Keeping the existing and raising diversity and heterogeneity in schools in general and chemis-

try classes in particular in mind one of the central pedagogical innovations in the here presented project is the implementation of a complex model for differentiation. The differentiation model takes into account students' diversity and heterogeneity in their personal interests, cognitive achievements, problem-solving skills, and (often poor) linguistic skills (Figure 2). The model provides guidance to structure highly differentiating teaching and learning environments, which are developed and tested for use in the SL environments within the project.

Each of the learning environments consists of three to five sub-topics. Each of them is composed of four to six individual experiments. The various experiments in each sub-theme differ in their complexity and cognitive demand. This allows matching students' prior-knowledge, cogni-

tive skills and problem-solving capabilities by a flexible adaptation of the learning environment with respect to the learning group.

The aim of differentiated instruction is to enable all students to solve each of the tasks on their own. Thus, all of the experimental tasks are developed with regard to a student-centered, inquiry-based pedagogy. Students work in groups of two or three. Garner et al. (2014) suggested that the SL is a place where failures can be experienced to be corrected and leading to better solutions. Thus, experimental instructions are given for doing the experiments in an open to guided inquiry approach (Blanchard et al., 2010). "Help Cards" and "Solution Cards" (that offer help on different levels) are provided to allow lower-achieving students to master at least a structured inquiry learning process.

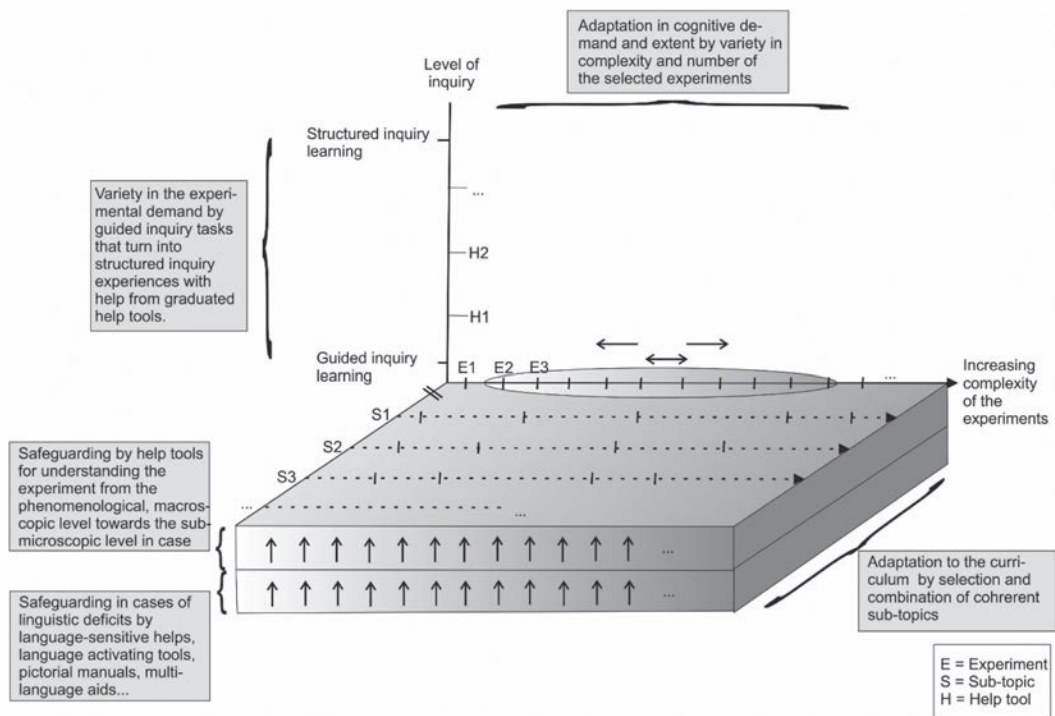


Figure 2. Model of differentiated learning environments in SLs (Affeldt et al., 2015).

Different tools are available to support students at different performance levels. "Help Cards" focus all the phenomenological-descriptive, the verbal-explanatory, the sub-microscopic, or formal-representational levels. They focus both

on content and the process of scientific inquiry. Further cards are provided to come up with linguistic heterogeneity among the students. Each set of laboratory instructions also contains a set of language sensitive tools (e.g., word lists, word

fields, etc.) as suggested in Markic, Broggy and Childs (2013).

Another innovation is a thorough focus on creative approaches towards experimental instructions, e.g., comics, as well as worksheets inspired by Internet forums, blogs, Facebook, Twitter, and other on- and off-line media (Figure 3). These tools aim on raising students' motivation and help to lower barriers towards the experimental tasks which are often caused by linguistic deficits among many of the students.

One example in practice: Exploring and Improving the Quality of Water

The SL learning environment Exploring and Improving the Quality of Water targets grade 5 and

6 students (age range 11–13) in lower secondary science education. The curriculum-relevant contents are properties of matter, methods for separation of matter, as well as water quality and waste water treatment. The learning environment shall promote a critical view on water as an essential everyday substance and the importance of water quality for our life and the environment. Knowledge about how water affects life and environment is needed to understand the necessity to protect the quality of water and to sensitize for a careful and economic use of water. Changes in students' attitudes towards the quality of water shall concern the limited availability of this natural resource.

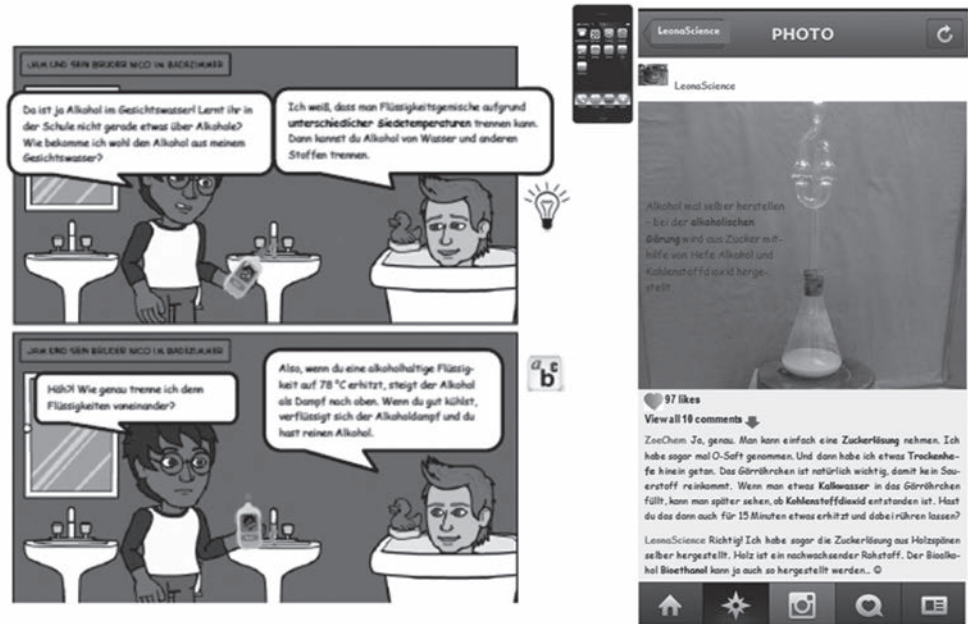


Figure 3. Two different creative approaches towards experimental instructions (comic on the left and entry in Instagram on the right).

The learning environment includes an offer of seventeen experiments divided into three sub-topics. The topics are selected based on their importance for sustainability and relevance to the school curriculum. The experiments in the sub-topics differ in the degree of cognitive demand and complexity (Table 2).

In sub-topic 1 the learners consider the properties of water in five different experiments. The contents are connected with contexts and issues

from life and environment. The learners explore the surface tension of water, the limits of solubility, the solubility of solids in water, the solubility of gases in water, and the different chemical states (solid, liquid and gaseous) of water in the different experiments. Each experiment usually is handled in 15 to 25 min.

Sub-topic 2 focuses on exploring water as a natural resource. In the experiments the learners inquire different mixtures including solid and

liquid substances solved in or mixed with water. The students evaporate water with waste and water with salt to discover and inquire the residues with the microscope. Learners are asked to link the findings from sub-topic 1 and 2 with the quality and the use of water in their everyday life. In sub-topic 3 various opportunities for the separation of mixtures, e.g., water and sand, water and oil, or wood, iron and water are given. The experiments show learners how methods for the separation of matter can be used to improve the quality of water. The use of activated carbon, sedimentation, decantation, different filters and distillation are compared and their potential for the treatment of waste water shall be discussed. The experiments vary in their complexity and their depth of cognitive as well as motoric skills from each experiment 1 to 5. In the most complex experiment, no. 5 of sub-topic 3, the learners are requested to clean a mixture of water with oil, sand, salt, iron filings, wood shavings and ink by using all the different methods for separation of matter.

Subtopic	Experiment	Content
The properties of water	1 Cleaning up after the party	Surface tension
	2 The over-salted water	Limits of solubility
	3 Which solids dissolve in water	Solubility of solids
	4 Gases in water	Solubility of gases
	5 Just water	Aggregate states
Exploring water as a natural resource	1 Exploring of mixtures	Solubility of different substances in water
	2 The magic water	Comparing water and lime water
	3 Hard and soft water	Lime in Water
	4 Evaporation of water samples	Evaporation
	5 Tiny substances very large	Microscope for microstructures
Different separation methods	1 Magnetic separation	Magnetism
	2 The magic powder	Purification by activated carbon
	3 Sedimentation	Sedimentation
	4 Decantation	Decantation
	5 Various filters	Filtration
	6 Distillation of salted water	Distillation
	7 The individual treatment plant	Different separation methods

Table 2. Experiments in the different sub-topics.

The differentiated instructions of this non-formal learning environment contain graduated learn-

ing tools. The tools are available to support students at different performance levels and allow all students, both lower- and higher-achievers, to participate in the inquiry process. Creative approaches using towards the experimental instructions are selected according to the age range of the students and their everyday lives. Thus, mainly comic illustrations were used in the experimental instructions of this learning environment.

Development and Evaluation

Method and Sample

The development of the learning environments follows a cyclical process of design, testing, evaluation and optimization. Students` questionnaires and teachers` feedback are used in each implementation phase. The student questionnaire focuses on the learner`s perception of the topics, instructional materials, selected pedagogies, and the language-sensitive design. It includes a total of 10 items with four-point Likert scales and two open-ended questions. The data interpretation is triangulated by relating the answers from the questionnaires with teacher observations and the observation protocols provided by the SL staff. Learning environments for the six different topics are currently implemented in all the four SLs at the above listed partner universities. So far, a total of 1091 students have visited the differentiated, non-formal learning environments in one of the four student laboratories. 748 of these students visited a non-formal learning environment in the SL in Bremen; 11 learning groups with a total of 244 students visited the learning environment Exploring and Improving the Quality of Water. Most of these students came from urban comprehensive schools with a particularly high rate of students having a migration background.

Findings and Discussion

The here presented results stem from students having visited the non-formal learning environment Exploring and Improving the Quality of Water in the SL in Bremen till October 2015

(N=244). Almost all students indicated that the experimental instructions encourage learning about chemistry. More than 90% of the participants agreed strongly or mainly to a statement corresponding to this (Figure 4).

concerning the personal interest of the students. Almost all students (over 90%) are in fully or mainly agreement with the statement that the tasks during the SL were interesting. The students' answers also indicated that the visit of the

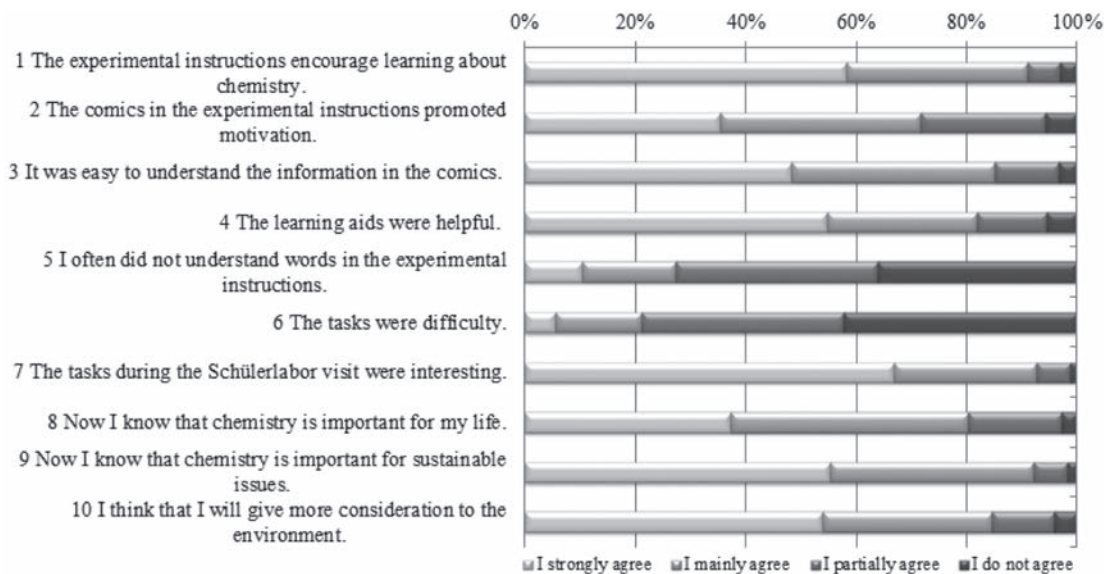


Figure 4. Results of the questionnaire-based study with a total of 10 items.

Connecting the experimental instructions with comics is deemed to be motivating by a large part of the students. A big group of students showed high level of agreement (about 40%), with another group of about 40% agreeing mainly. Additionally, almost half of the students (50%) indicated strongly and about 40% indicated mainly that it was easy to understand the information in the comics. The vast majority of the students responded with at least strongly and mainly agreement that the learning “Help Cards” for the experimental instructions were helpful (about 80%). Only a small percentage of the students fully or mainly agreed to the statement that they did not understand the words in the experimental instructions (about 25%) and that the tasks were difficult (about 20%). These are points for further improvement in the next rounds of implementation.

The exact opposite is shown in the statement

SL had positive influence on their opinion about science and changed attitudes towards chemistry in particular. Roughly 80% strongly or mainly agreed that they know now how important chemistry is for their personal life. More than 90% of the students met high levels of agreement with the statement that they know (after the visit of the non-formal learning environment) that chemistry is important for sustainability issues. Additionally, over half of the students indicated that the visit of the SL will have an influence on their behavior. More than 50% fully and roughly 30% mainly agreed that they think that they will give more consideration to the environment.

Answers to the open-ended questions and teacher's feedback support the indications of very positive overall feedback. Both students and teachers expressed that the visit to the SL contributed to raising the students' motivation towards science learning, as well as increasing the overall

learning effects with respect to social skills. The teachers especially valued the creative design of the instructions, particularly with regard to the everyday lives of their students. These initial results indicate that such learning environments in their differentiated form, including the various combinations of innovative pedagogical tools, have potential to promote students' interest in science and increase motivation. The findings of parallel experiences from other previously implemented learning environments focusing on chemistry learning in sustainability contexts (Garner et al., 2015; Salmi, 2003).

Conclusions

Mischnick and Faustmann (2014) stated that if learning environments are well-adapted, even lower-achieving students can become highly motivated and profit from practical work offered within the SLs. In the SL environment described here, the students were exposed to contextualized learning environments with a set of pedagogical innovations. These innovations aim at opening science learning to all learners with the support of multi-differentiated learning environments which take the learners' personal interests, varying cognitive capabilities, and heterogeneous linguistic skills into account. This project intends to promote student motivation and science learning, but also to provide improved learning opportunities on topics from chemistry relevant to sustainability to all learners, both with educationally advantaged and disadvantaged backgrounds (Affeldt et al., 2015).

The overall student and teacher feedback is very positive. The different topics, as well as the pedagogies applied, were considered as being interesting, relevant, and feasible. Connecting science learning to authentic issues from the sustainability debate in the SL proved again to be motivating and meaningful to the learners as already reported by Garner et al. (2014). Students' and teachers' feedback provided initial indications that approaching science learning through

sustainability-relevant topics using the new model of differentiation is an even more promising approach (Affeldt et al., 2015). The given structure of the SL environments can help make learning experiences more manifest and to allow a larger number of students to find their own approach to science learning.

The case study described in this paper was also focusing on changes in learners' attitudes towards science learning, sustainability, and the personal as well as societal dimension of chemistry. The findings indicate that the students started recognizing the importance of chemistry for their personal life and for sustainability issues. The study suggests that visits of SL environments focusing sustainability can also have a positive influence on students' behavior in their everyday life, although this influence should not be overestimated. Further research will now focus differences concerning students' with privileged and disadvantaged educational backgrounds. In doing so, a special focus will be put on differences between students with varying educational biographies, achievement levels, and attitudes towards science education and on the various creative approaches used in the experimental instructions.

Finally the presented studies shows that the developing of working sheets and materials by following the presented model of differentiated learning environments help students in their learning and understanding of scientific content and language while working in student-centered learning environments. Starting from here, the chance is to be seen to adopt the model in the development of teaching and learning materials for chemistry lessons in schools and to help chemistry teachers in planning their lessons and dealing with raising heterogeneity and diversity in their chemistry classes.

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Abstract

What: For many of us who teach chemistry, the “what” of sustainability means learning a new body of knowledge. I will speak to the learning curve, having climbed it as the editor-in-chief of *Chemistry in Context*, a project of the American Chemical Society. I also will discuss the definition of the term itself, sustainability. Finally, I will describe how making connections is of key importance as students learn about sustainability. Just as they make connections in the sub-microscopic world of atoms and molecules, our chemistry students also need to make connections in the real world around them.

How: The “how” also has a learning curve. Our expertise lies in teaching chemistry problems that have answers in the back of the book. Teaching sustainability involves envisioning solutions to complex problems that are difficult to describe and challenging to remedy. The answers to such problems are not in the back of the book.

Why Now: This one is easier. The time is now because our students (and future citizens) need it, welcome it, and ask for it. So does our professional societies. “Chemistry for a Sustainable World” is a four-way win: for our students, for our discipline, for our communities, and for our planet.

Introduction

“Version 2.0” appears in the title for a reason: This paper is an update to events that began in 2010 under the same title. In this year, the 239th national meeting of the American Chemical Society (ACS) was held in San Francisco, California. The meeting theme was “Chemistry for a Sustainable World” (Figure 1).



Figure 1. Logo for 239th national meeting of the American Chemical Society, San Francisco, California, United States.

At this national meeting, Cathy Middlecamp and Mary Kirchhoff co-organized a symposium entitled “Sustainability in the Chemistry Curricu-

lum: What, Why Now, and How?” This symposium brought together over 30 speakers, filling the room to capacity. Here is the symposium description:

“You may have noticed the buzz around campus. People are talking green. Energy saving is in vogue. Campus vehicles, food services, and residence halls are all getting in on the sustainability act. In contrast, the undergraduate curriculum (in general) and the chemistry curriculum (in particular) has been far slower in reflecting any changes. What are the different meanings ascribed to the term “sustainability”? Why are campus administrators, professional societies, and government agencies now interested in it? Why the urgency? What models for teaching and learning currently exist? This symposium welcomes papers that address these and related questions.”

A monograph in the ACS Symposium Series was released a year later (Figure 2). The Editor’s Preface begins: “We dedicate this book to

our many colleagues who have dedicated their talents to rethinking the undergraduate chemistry curriculum. They have explored and tested new pedagogical approaches in order to better convey the excitement and centrality of chemistry. They have contributed to the research on how people learn chemistry. We are in their debt. [1]"

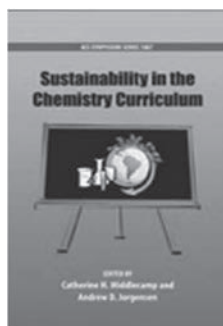


Figure 2. American Chemical Society Symposium Series Sustainability in the Chemistry Curriculum, ACS Symposium Series #1087, Edited by Catherine Middlecamp and Andrew Jorgensen, 2011 [1].

Several sustainability-related events followed this 2010 symposium. In 2011, one such event was the release of the 7th edition of Chemistry in Context, a project of the ACS [2]. Chemistry in Context is an undergraduate textbook for non-science majors, including pre-service teachers, that engages student in learning chemistry through real-world societal issues such as air quality, acid rain, energy, food, and plastics. In the 7th edition, a new chapter was added to the book: "Chemistry for a Sustainable World." This chapter, included in the current 8th addition as well, is available free via a download from the ACS website [3]. The final section of this chapter includes a statement from Our Common Future:

"In the middle of the 20th century, we saw our planet from space for the first time. .. From space, we see a small and fragile ball dominated not by human activity, but by a pattern of clouds, oceans, greenery, and soils. Humanity's inability to fit its activities into that pattern is changing planetary systems, fundamentally. Many such changes are accompanied by life-threatening hazards. This new reality, from which there is no

escape, must be recognized – and managed [4]." The members of the author team of Chemistry in Context echoed these words:

"We agree. This new reality must be recognized. There is no escape. And all of us – students and teachers alike – have important roles to play [3]."

Another event that lent weight to the teaching of sustainability-related content was the publication of research studies on how people learn. In the United States, one of the most widely read publications was Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering, published in 2012 by the National Academies Press [5]. A 2015 article built off this research, presenting the evidence for bringing sustainability to our undergraduate classrooms:

"A growing body of evidence shows that infusing sustainability into undergraduate courses and programs can simultaneously benefit institutional goals, student learning outcomes, and society at large [6]."



Figure 3. American Chemical Society Symposium Series Teaching and Learning about Sustainability, ACS Symposium Series #1205, Edited by Irvin J. Levy and Catherine H. Middlecamp, 2015 [7].

In 2014, a second sustainability symposium was co-organized by Irvin Levy and Cathy Middlecamp. This one took place at the 248th national meeting of the American Chemical Society, again held in San Francisco. The American Chemical Society has over 20 technical divisions, each representing a field of chemistry such as inorganic, nuclear, organic, fuels, polymers,

and the environment. This symposium brought together speakers from each technical division. Speakers were given the assignment of describing how their field of chemistry could contribute to a sustainable future. After the symposium, a second book in the ACS symposium series was released (Figure 3) [7].

To summarize, in the United States, a 2010 symposium at a national meeting launched a conversation among chemistry educators about sustainability in college curriculum. This paper acknowledges that much work has been accomplished and much has been learned in the years that followed. Using the framework from the author of this paper's contribution to Sustainability in the Chemistry Curriculum, three topics relating to sustainability will now be discussed: What is sustainability? How can it be learned? And why is now the time to be learning it?

What is Sustainability?

What should our students understand about sustainability? When instructors present a new term, they often begin by defining it, a useful point of departure for any new concept. However, the definition of sustainability is problematic in several regards. One reason is that many definitions are for terms using sustainability in its adjective form "sustainable," e.g., sustainable development or sustainable world. Consider, for example, this statement about a sustainable world in a recent publication by the U.S. National Science Foundation:

"A sustainable world is one in which human needs are met without sacrificing the ability of future generations to meet their needs. Addressing this formidable challenge requires a substantial increase in our understanding of the integrated system of society, the natural world, and the impact of human activities on planet Earth [8]."

Similarly, here is a statement by the United Nations Educational, Scientific and Cultural Organization (UNESCO) on sustainable development:

"Sustainable development has been variously

defined and described. It is not a fixed notion, but rather a process of change in the relationships between social, economic and natural systems and processes. The World Commission on Environment and Development, for example, defined sustainable development in terms of the present and the future: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs [9]."

Another reason that finding a definition of sustainability is problematic is that no single definition has been agreed upon. For example, an internet search will reveal many definitions. While complementary to each other, these definitions do not all align. Furthermore, although the definition of sustainable development most widely used is that cited in the previous paragraph, no single definition of sustainability seems to be favored. Given this state of affairs, by what means does an instructor convey the essence of the term sustainability to students in a chemistry classroom?

First, an observation. My students at the University of Wisconsin-Madison – as well as most students in the United States – have heard the term "sustainability" prior to coming to my course. They know the term from high school, from the media, and from other college courses. These students have at least an intuitive sense of the importance of a future that is sustainable; they even may be able to quote the Brundtland definition: "Sustainable development ... meets the needs of the present without compromising the ability of future generations to meet their own needs [9]."

Second, the legitimacy of stories. As a teaching tool, stories are one way of providing a point of entry into conversations about sustainability. Teaching is not telling; rather, teaching involves engaging the listener in learning. Stories engage the listener; this mode of teaching has withstood the test of time.

Recognizing the prior knowledge of students and the power of stories, the author tells a personal story from a setting familiar to her students: a bi-

cycle trail on campus. When vehicles and pedestrians are nearby, navigating a bike trail requires the full attention of a cyclist.

The story begins with a photograph (Figure 4). It shows a portion of the bike trail with a bend so that cyclists can cross a set of railroad tracks at a right angle. If cyclists to hit the tracks head on, the chances are minimal that their front wheel will get caught in the tracks, resulting in a nasty fall.



Figure 4. A campus bike path at the point where it crosses a set of railroad tracks. This photo was taken at a rare moment with no vehicles, bicycles, or pedestrians in sight.

The story continues:

“One fall semester day, I had successfully cycled through this intersection, watching carefully for the cars and pedestrians. In addition, I managed to keep my wheels perpendicular to the track bed, so as to cross the rails uneventfully. While so intently focusing on path across the tracks, I missed seeing what was on the tracks. A locomotive! It was chugging along, pulling several coal cars to our campus heating plant. Once I cleared the tracks, I heard the train whistle and looked up in horror. Luckily the engineer had spotted me, the unwitting cyclist who somehow had missed all the cues, and did not sound the horn until I was safely clear of the intersection. How could I miss the train? In hindsight, it is no surprise. The simplest explanation was sensory overload. As I narrowed my focus, intent to watch for pedestrians and nearby cyclists, I did not look up. It simply is not possible to pay atten-

tion to everything at once. Even so, I needed to look up! When I now cycle through this intersection, I always do [10].”

The point of the story? Looking up is no easy task for an instructor busily engaged in the day-to-day activities on campus. Looking up is no easy task for our students as well. But it is important to look up now and then to find and keep our bearings.

Unlike a locomotive that warns of its presence by sounding its horn, the metaphorical locomotives coming down the train tracks in our world have no whistles. Changes occur silently. For example, discarded prescription drugs are making their way into the drinking water. Micro-sized pieces of plastic are accumulating in the oceans. Carbon dioxide concentrations are rising in the atmosphere. Sea levels are rising as well. The tundra quietly thaws and releases methane. Species blink out of existence with neither with a bang nor a whimper.

At one time or another, all busy people – including students and their instructors – experience the stress of sensory overload. In preparing their courses, instructors have important concepts to “cover” so that students will be prepared for future chemistry courses, if not for future professions in science, engineering, and medicine. Students have assignments to complete, they must work jobs to pay the bills, and they have family obligations to meet.

However, as we narrow our focus to stay safe in one regard, we become at risk in other regards. We miss things that threaten us, our families, our friends and our colleagues. Possibly missing things even puts the future of our discipline at risk. Everybody has a responsibility to look up.

How Can We Teach Sustainability?

A. Defining sustainability

What should instructors know about teaching sustainability? I asked my students this question in my environmental science course in the 2014 spring semester and received over 100 responses.

Here are five of them, reprinted with their permission.

"I would like the professors to hear your train story."

"Before we can hope to make any change in the world, one must take a step back, get the big picture and truly understand how everything is interconnected."

"... the most important thing is to figure out how it applies directly to your life and let that inspire you to make a difference."

"Give concrete examples of small easy things of small easy things to do; those will stay with students the longest."

"I am politically conservative, but the issues brought up throughout this class are extremely important. All students have a right to know about sustainability and what it will take to live in a sustainable world."

The first item in this list provided the impetus for the story in the previous section. The second item echoes the message of this story; namely, to take time to view the bigger picture. The third and fourth speak to the need to connect sustainability to the lives of students, a real-world context that illustrates what it will take to live in a sustainable world. And the final item forms part of the rationale described in a later section of this paper.

B. Sustainability content and concepts

Real-world contexts are important to learning! However, instructors may claim that they cannot devote time to a real-world context because their students must first learn the basics of chemistry: facts, rules, concepts and problem-solving techniques. Sustainability offers a path to join context and content, including the content of sustainability.

Reflect, for a moment on the nature of chemical content. It is a complex interplay among learning about the atoms and molecules that make up matter (microscopic view), representing these atoms and molecules (symbolic view), and the behavior of matter in the world (macroscopic view). See Figure 5a.b

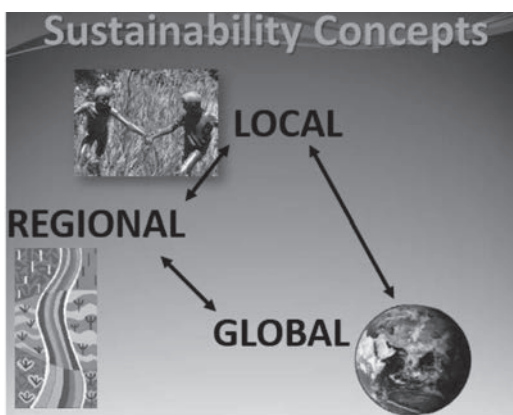
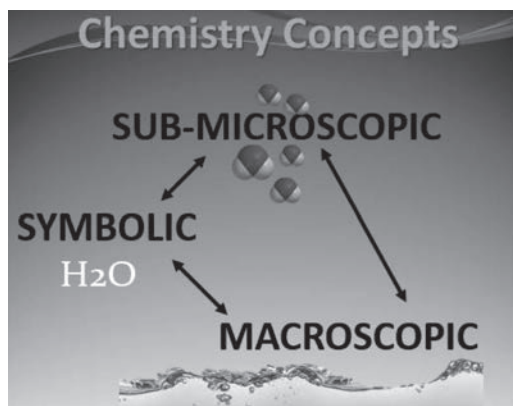


Figure 5. a. Three interrelated ways of viewing chemistry concepts
b. Three interrelated ways of viewing sustainability concepts

Similarly, concepts in sustainability are simultaneously played out in three arenas. The air we breathe and the water we drink can be viewed locally, regionally and globally (Figure 5b). Each is important as students develop an understanding of the issues involved. Concepts that may be needed in discussing sustainability-related topics include cradle-to-cradle, ecological footprint, shifting baselines, tragedy of the commons, external costs and the Triple Bottom Line.

Let's work with one of these concepts, the tragedy of the commons, i.e., when a common held in common is damaged or destroyed. Water, air, and soil belong to all, are used by many, but nobody in particular is responsible for them. If resources such as these are degraded, then human illness, premature death, the loss of crops, and

To help students understand the cause of the pollutants monitored on the maps, instructors need to make connections. These can be of four types, as shown in Figure 9.

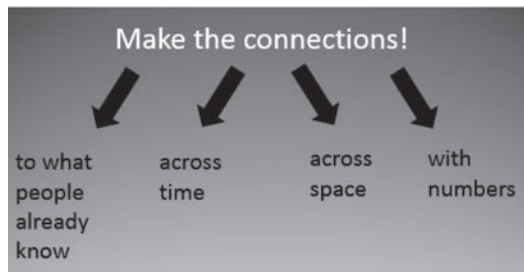


Figure 9. Examples of the types of connections instructors can make to help their students learn about sustainability.

Making connections to what students already know (or in some cases what they think they know) can be a relatively straightforward process. For example, using their prior knowledge of sustainability was mentioned earlier in conjunction with defining sustainability. The same is true for student prior knowledge about air quality. Students may know the two primary gases in the atmosphere (N_2 and O_2) and may have heard that the concentration of CO_2 has now risen above 400 ppm. However, students are less likely to be able to name more than one or two air pollutants, trace these across time and space to their origins, and connect them to any numerical values. They may wrongly think that CO_2 is 4% of our atmosphere or even higher. The key is to find out what students know (and don't) and then start from there.

Connections across time and space to the sources air pollutants are more difficult, because of the degree of separation involved. When a student hits a light switch or eats a hamburger, the sources of the primary pollutants (e.g., fine particles, $PM_{2.5}$ and PM_{10}) or the secondary pollutants (e.g., O_3) are likely to be kilometers away. These sources include vehicles, industry, agriculture, power plants, some of which students may never have seen up close. They may not realize that actions taken either in the past or at a distance are affecting not only their health but also the well-

being of their community.

Consider fine particles, for example. These are monitored in two categories: $PM_{2.5}$ and PM_{10} . The former is 2.5 microns or smaller (more dangerous) and the latter is 10 microns or smaller. Both originate from multiple sources and have varying chemical compositions. Some are pieces of soot from incomplete combustion in engines or wild fires; others are pieces of dirt or crystals of compounds such as ammonium nitrate. Still others are tiny pieces of a material such as rubber from tires on a roadway. These fine particles may have been emitted days ago, remaining suspended in the air until brought down by rain, mist, or snow. A recent research article in which David M. Broday, Technion Institute of Technology, Haifa, identifies fine particles as "a leading risk factor" in global human health [13].

Consider tropospheric ozone as another example. Ozone is monitored via spectrophotometry at both ground level (troposphere) and higher altitude (stratosphere). At ground level, ozone is a secondary pollutant meaning that it forms in the atmosphere from other pollutants. Ground-level ozone forms the necessary ingredients are present: NO emissions from engines or power turbines, volatile organic compounds (VOCs) in the air from human or natural sources, sunlight, and a long enough period of daylight for NO_2 to form and photolyze to NO and O. Once formed, ozone rapidly reacts with whatever it encounters. In vegetation, ozone causes leaf mottling or necrosis of the tips of needles. In humans, ozone results in a burning sensation in the eyes and in irritation to lung tissue. Because of its reactivity, ozone does not persist long in the atmosphere after the sun sets.

Connections with numbers perhaps come the most naturally to science instructors. Consider a unit of electricity, a kilowatt-hour. Although most college science instructors teach energy using the SI unit of the joule, the kilowatt-hour is widely employed as a unit of energy many in real-world contexts, including the utility bill delivered to most residences. Because carbon-

based fuels are burned to produce electric power, a kilowatt-hour connects to a known mass of CO₂ emitted.

The CO₂ emissions of a unit of electricity (a kilowatt-hour) in a given region depends on the mixture of fuels employed at the electrical power plants. A typical value of the emissions for one kilowatt-hour produced in a region with a mixture of fuels would be 0.8 kg CO₂ [14]. The carbon dioxide emissions would be larger if coal were the predominant fuel; they would be smaller if more natural gas were burned, if more renewable energy sources were used, or if nuclear power was part of the mix. Table 1 gives the % carbon for different carbon-containing fuel sources. Similarly, a kilowatt-hour connects to a known amount of air pollutants. Depending on the fuel mixture, these pollutants include CO, NO and NO₂, SO₂ and fine particles.

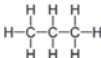
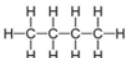
Fuel	Structural Formula	% carbon
Methane (primary component of natural gas)		75%
Ethane		80%
Propane		82%
Butane and higher		83%
Anthracite coal	N/A	>90%

Table 1. Percent carbon for different fuels. The emissions of CO₂ per kilowatt-hour of electricity depend both on the heat content of the fuel and its % carbon.

Making connections is of key importance as students learn about sustainability. Just as they make connections in the sub-microscopic world of atoms and molecules, our chemistry students also need to make connections in the real world around them.

Why is now the time to be teaching sustainability?

Of the questions posed in this paper, this one is easiest to answer. At least four reasons can be cited for why now is the time to teach sustainability in our introductory science courses:

- 1. We've never had a better rationale.
- 2. We've never had better tools.
- 3. We've never had a greater need.
- 4. We've never had so much to lose if we don't act.

These four reasons to teach (and learn about) sustainability are important to all people in all countries of the world. They need to be expressed in all languages. To honor the host college for the symposium in which this paper was presented, Table 2 provides these four messages in Arabic.

1 - لم يَسْتَقِ أَنْ يَكُونَ لَدُنْيَا مُبَرَّرٌ لِلْعَمَلِ أَحْسَنَ مِمَّا لَدُنْيَا فِي هَذِهِ اللَّحْظَةِ!
2 - لَمْ نَكُنْ نَمْتَلِكْ أَدَوَاتَ أَفْضَلَ لِلْعَمَلِ مِمَّا يَتَوَقَّرُ لَدُنْيَا أَلَا!
3 - لَمْ نَكُنْ فِي حَاجَةِ أَمْسٍ مِمَّا نَحْنُ فِيهِ أَلَا!
4 - إِنْ لَمْ نَعْمَ بِالْمُبَادَرَةِ الْآنَ، فَمِنْ مَا سَتَقْدُهُ لَا يُعَادِلُهُ فَقْدُ!

Table 2. Why now is the time to teach and learn sustainability.

The time is now to teach sustainability because our students who are our citizens of today and tomorrow, need it, welcome it, and ask for it. "Chemistry for a Sustainable World" is a win for more than just our students. Sustainability a four-way win: for our students, for our discipline, for our communities, and for our planet.

Conclusions

Many professionals in many countries, including my own, the United States, have worked to bring sustainability to the college chemistry curriculum. The work is well underway. Even so, the questions addressed in this paper remain useful guides as we continue the work: What is sustainability? How do we teach sustainability? And what is the rationale for teaching it now? Several points made in this paper can be helpful to keep in answering these questions.

First, stories are a powerful teaching tool. "The

world is not made up of atoms; rather, it is made up of stories” (source unknown).

Second, a story in this paper reminds us to stop, look up, and take in the bigger picture. Not only does the big picture have value in and of itself, but also taking time to stop and look up might keep you from getting hit by a real or metaphorical train.

Third, everything is interconnected. Some of these connections may be difficult for us and for our students to perceive, because they are separated from us in time or space. Even so, they have profound implications and are worthy of our attention.

Finally, now is the time. We’ve never had a better rationale. We’ve never had better tools. We’ve never had a greater need. We’ve never had so much to lose if we don’t act.

Acknowledgments

The author gratefully acknowledges the many colleagues who helped her better understand sustainability, its intricacies, and the rationale for including it in the curriculum. These include members of the Chemistry in Context author team, most recently Karen Anderson, Anne Bentley, Michael Cann, Jamie Ellis, and Katie Purvis-Roberts, colleagues at the University of Wisconsin-Madison Office of Sustainability, most recently Ann Terlaak and Faramarz Vakilzadeh, and graduate students at the Nelson Institute for Environmental Studies, most recently Kata Dosa, Travis Blomberg, Tom Bryan, and Tim Lindstrom.

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Abstract

Project Chain Reaction is a three-year (2013-2016) project funded by the FP7 program of European Commission. Chain Reaction aims to develop Inquiry Based Science Education (IBSE) across twelve partner countries. The project provides interactive and engaging IBSE professional development to teacher education professionals from each participating country using tried and tested inquiry based science resources. Ilia State University is a consortium member of the project and implements the project activities in Georgia. The Chain Reaction project offers 11 of the original Pupil Research Briefs (PRBs), which are based around "The Earth and the Universe" topic areas. Several studies were done during the implementation of the project. One of them is Kelly's Construct Theory, which is used to study the changes of Georgian science teachers' constructs of IBSE.

Keywords: Project "Chain Reaction", IBSE competences, Teachers constructs

Introduction

After the collapse of Soviet Union in 1991 several Educational Reforms were implemented in Georgia. The last one began in 2004. Since 2004, several versions of a new national curriculum for both elementary and secondary schools were piloted and implemented. Within the new science curricula much attention is paid on inquiry-based and student-centered approach (Kapanadze, Janashia & Eilks, 2010; Slovinsky, 2012). Several versions of new textbooks are appeared in Georgian Schools with the new content, but teachers still aren't prepared to follow the process. The school laboratories aren't equipped accordingly and the teachers do not possess the skills to conduct the learning process according to curricula. Science teachers' education is one of the key points of the reform. New Standards for the teachers were developed and approved by the Ministry of Education and Sciences of Georgia (TPDC, 2012). These new standards identify the specific competencies required of the science teachers, which should allow them to effectively achieve the desired outcomes defined in the

national curriculum. "Teachers House", which is officially responsible for teacher training in Georgia, organized centralized short-term trainings. These trainings are based on traditional approaches of science education and teachers don't get any practical support during the trainings. Traditional science education focuses on the aspect of theoretical knowledge "what we know", while inquiry based science education aims to explore "how we know" and gives the understanding of scientific processes and nature of science itself (Bartholomew et.al. 2004). The reform is ongoing, but the low quality of science teaching in schools and its impact on the students' motivation is often reported during the conferences and meetings in Georgia.

Ilia State University (ISU) offers pre-service and in-service teacher preparation programs and is one of the major universities in Georgia with this programs. Educational projects, funded by EU commission, supporting the implementation of new approaches in science teaching have been realized in Georgia; Ilia State University was the consortium member and implemented

project activities in Georgia. Projects such as PROFILES (Professional Reflection-Oriented Focus on Inquiry-based Learning and Education through Science) (PROFILES, 2010) and Chain Reaction (Chain Reaction, 2013) support the implementation of IBSE (Inquiry Based Science Education) in participating countries. This paper gives insight how the implementation of project Chain Reaction helps to strengthen Education for Sustainable Development through inquiry-based approaches.

Project Chain Reaction

”Chain Reaction” is a three-year (2013-2016) project funded in the frame of FP7 program of European Commission. Project aims to develop Inquiry Based Science Education (IBSE) across twelve partner countries. The effectiveness of inquiry based learning in science education is discussed in books and scientific papers (EU Commission, 2007, National Research Council (2004), Kapanadze, M., & Slovinsky, E. (2014), Bybee, R.W. (2004), Anderson, R. D. (2002)). These studies stress also importance of real context in science classroom (E. Alvarado & P.R. Herr, 2003)

The resources used in the ”Chain Reaction” project are based on Pupil Research Briefs (PRBs), which are problem solving and inquiry based classroom activities covering different topics from space science to environmental education, to the impacts of climate change. Using critical thinking, reasoning and problem solving skills, students in the 14-16 age groups work together to research scientific scenarios.

Participants of Chain Reaction Project work with 11 PRBs which are based around Earth and Universe topic areas. These PRBs were designed at the Science Education Centre at the Scheffield Halam University, UK. The original PRBs are modified and form the EUPRBs. These EUPRBs are:

Collision Course	calculating the chance of a comet or a large meteorite hitting the Earth
Cosmic Web Site	creating a Website to explain the Big Bang theory
ET Phone Earth	writing a journal article about the search for extraterrestrial intelligence
Green Heating	carrying out investigations into energy transfer in solar panels
Green Light	advising on the use of a low energy compact fluorescent light bulb
Mars-ology	investigating the factors which cause Martian volcano shapes
Out of Site, Out of Mind	investigating the lining material for a landfill site
PHEPPS	improving the design of a portable hydroelectric power plant
Plants in Space	investigating the factors which are important in making a life sustaining unit for use on long space flights
Feed the World	investigating fertilisers and producing educational leaflets for use in developing countries
Ozone Conference	running a classroom conference on ground level and stratospheric ozone

Table 1. Earth and Universe Pupil Research Briefs

Chain Reaction aims to include a large number of students and teachers across twelve partner countries during the three year duration of the project. Each year five schools from each country with their two science subject teachers are participating in the project. Their work is summarised in presentations that are done during the national conferences within the country or international conferences once a year.

Chain Reaction project has seven key objectives (Chain Reaction Project Proposal, 2013)

1. Adapt and disseminate a set of themed inquiry based science resources (PRBs) which have been adapted to meet each partner’s cultural and curricular needs, to be used for briefing teachers and in the classroom;
2. Promote the use of IBSE in secondary schools across the 12 partners via a programme of teacher development which will engage young people in science through student-led inquiry based research;
3. Help bridge the existing gap between science teachers and the science education community;
4. Promote a European teacher network;
5. Dissemination of resources (EUPRBs) and effective practice;
6. Effective evaluation and reporting;
7. To hold 36 national and three international celebration events for teachers and students.

Brief overview of the project is given below:

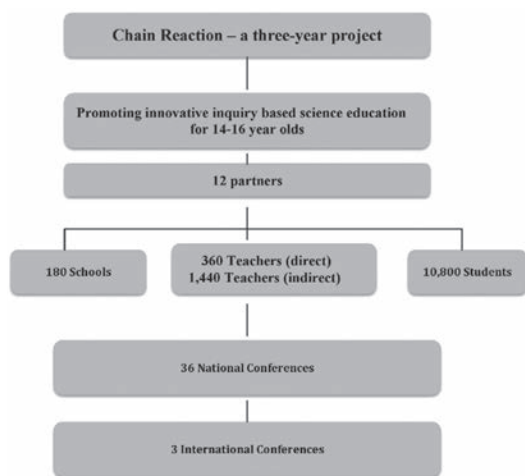


Figure 1. Project overview

EUPRBs implementation in Georgia

The EUPRBs are a way to develop inquiry-based learning in science. During the implementation of PRBs students realize how science works and also applications and implications of science. Students learn:

- How scientific data can be collected and analyzed;
- How the interpretation of data, using creative thought, provides evidence to test ideas and develop theories;
- How explanations of many phenomena can be developed using scientific theories, models and ideas;
- That there are some questions that science cannot currently answer, and some that science cannot address;
- Plan to test scientific ideas, answer scientific questions, or solve scientific problems;
- Collect data from primary or secondary sources, including ICT sources and tools;
- Work accurately and safely, individually and with others, when collecting first-hand data;
- Evaluate methods of collection of data and consider their validity and reliability as evidence;
- Recall, analyze, interpret, apply and ques-

tion scientific information or ideas;

- Use both qualitative and quantitative approaches;
- Present information, develop argument and draw a conclusion, using scientific, technical and mathematical language, conventions and symbols and ICT tools;
- About the use of contemporary scientific and technological developments and their benefits, drawbacks and risks;
- To consider how and why decisions about science and technology are made, including those that raise ethical issues, and about the social, economic and environmental effects of such decisions;
- How uncertainties in scientific knowledge and scientific ideas change over time and about the role of the scientific community in validating these changes.

Six EUPRBs were implemented during three years of Chain Reaction progress in Georgia. These EUPRBs are:

- Green Light
- Green Heating
- Plants in Space
- Feed the World
- Out of Site, Out of Mind
- PHEPPS

All these PRBs were translated in Georgian language and adapted for national needs. These contexts and tasks, alongside the interactive and “hands on” approach of the EUPRBs, aims to appeal to both a broad range of abilities and to both genders.

In this paper we’ll present some of them.

Green Light

The aim of this Brief is for students to learn more about Compact Fluorescent Lamps (CFLs) and LED, the energy - efficient alternatives to ordinary light bulbs. The context for the Brief and the students’ roles are based on a real-life issue. The students, working in groups, are invited to take the role of members of the Energy Trust’s

Energy Efficient Lighting Committee, which was organized during Rio Earth Summit 1992. Their task is to produce a promotional newspaper advertisement to encourage the public to switch over to CFLs or LED. As well as covering basic information about light bulbs and costing electricity, they learn about the shortcomings of using ordinary filament bulbs and the benefits of CFLs and LED. They also learn about the results of market research into why some people switch to using CFLs or LED and why others do not. Students have done measurements and compared the energy consumed by light bulbs within a month with fluorescent lamp and LED lamp (Fig. 2).

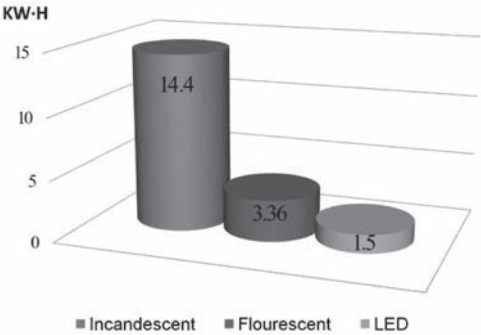


Figure 2. Electrical energy (KW.H) consumed per month

Students' conclusions are listed below (Fig. 3, Fig. 4):

- Illuminance of 100W incandescent lamp equals to the illuminance of a fluorescent lamp with 5 times less wattage and LED lamp with 13 times less wattage;
- Efficacy of 100W incandescent lamp is 7 times less than that of 20Watt fluorescent lamp, and 21 times less than that of 8W LED lamp;
- Overall efficiency of 100W incandescent lamp is about 3%, whilst fluorescent lamp of identical illuminance has an overall efficiency of about 20%, LED lamps of identical illuminance have an overall efficiency of 51%.

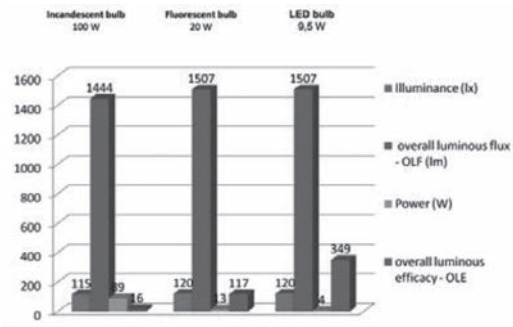


Figure 3. Photometric measurements

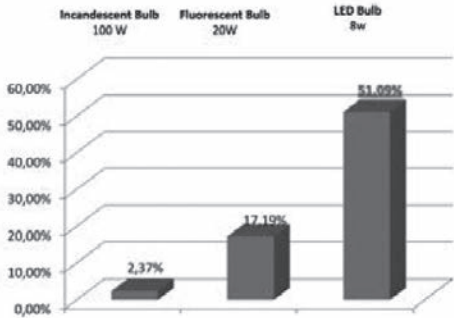


Figure 4. Overall luminous efficiency

Students have calculated the individual expenses of incandescent, fluorescent and diode bulbs over the course of seven years (LED exploitation minimum). They've done comparative analysis, which is given on Fig.5.

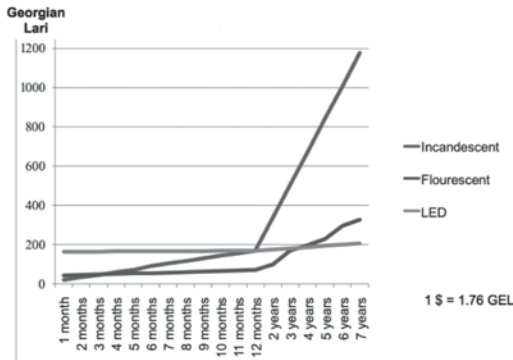


Figure 5. Costs of different bulbs over time periods (month, year)

Students' discussions:

Incandescent bulbs are perhaps the cheapest available option, though costs associated with consumptions are likely to increase with the time. As for the luminescent lamps, they

are relatively expensive when contrasted to the incandescent ones, and cheaper when compared with the diodes. Differently from the incandescent lights, whose expenses keep rising over the years, LEDs not only rapidly reimburse their purchase price but also prove profitable in the long run. It is for these reasons that fluorescent lights, though far behind their incandescent counterparts in terms of annual expenses, can never compete with the highly impressive record of the diodes.

Based on students' results it is clear the preference of LED to ordinary light bulb.

Green Heating

In Green Heating students carry out investigations to find out which colour and type of surface is best for absorbing infrared radiation so that it can be used in a solar panel. They are given background information about solar panels and about infrared radiation from the Sun, and they are provided with information about how a scientific investigation is conducted. Students are constructing their own model of solar panel and planning the use of it for the school water heating purposes.

Students have done measurements and calculations and got different models of solar panels. Some of the models are presented on Fig. 6

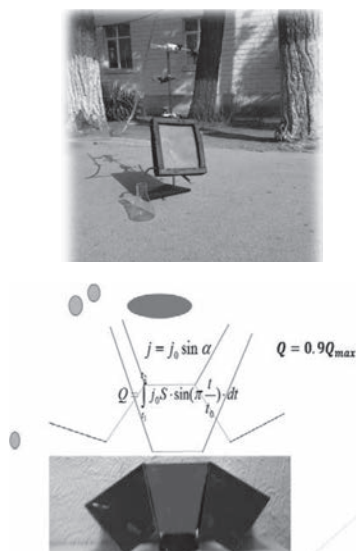


Figure 6. Models of solar panel

Students have done their measurements at SA-LiS laboratory at Ilia State University with PAS-CO sensors. Results of the experiment, when the students have done measurements which colour of surface is best for absorbing infrared radiation are presented on Fig. 7

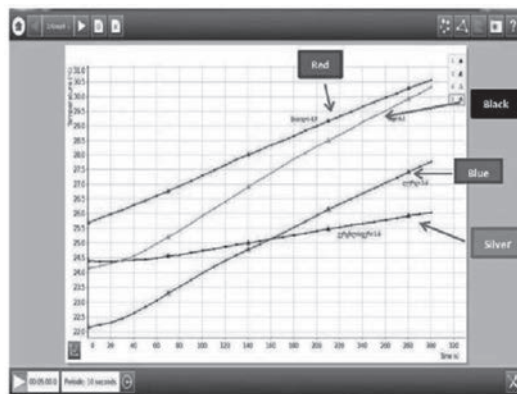


Figure 7. Measurement of temperature for different colour surfaces

Teacher Professional development in Chain Reaction

In order to achieve the project aims, Chain Reaction team in Georgia supports the adaption, creation and development of materials and modules for teaching and learning science to enhance Inquiry-Based Science Education. Before project implementation in schools all 30 participant teachers have been briefed at Ilia State University. It consisted of at least 50 hours of coursework (seminars, lectures, workshops etc.).

Fig. 8 presents the model of the CPD programme which Ilia State University team in Georgia created and followed, in consideration of the Georgian science teachers' professional needs.

During the CPD programs teachers were working on different activities. All of them were focusing on issues connected with everyday life leading to a scientific question and on a student-centred emphasis on scientific problem solving using inquiry. The sessions were oriented to enhancing specific professional skills of the participating teachers, such as experimenting, investigating, creating, cooperating together. Creative thinking, problem solving and designing learning

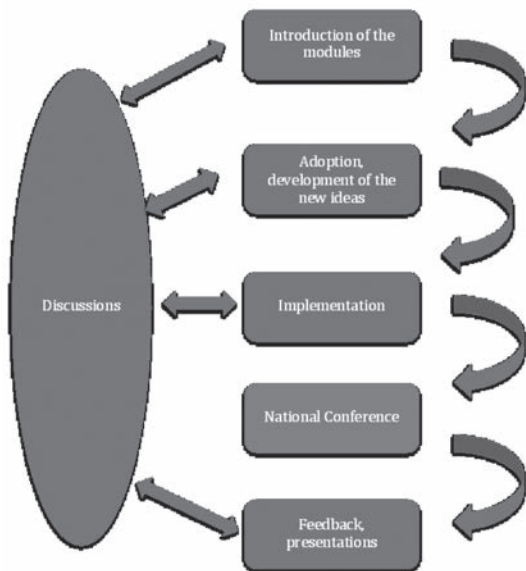


Figure 8. Model of the CPD programme at Ilia State University

environments emphasizing socio-scientific issues and concerns, were introduced by the project staff as well as discussed and worked out by the participating teachers.

In the frame of the Chain Reaction project, different workshops and seminars were organized focusing on how to realize IBSE in Georgian science classrooms.

Fig. 9 presents the Georgian teachers working at SALiS laboratory at Ilia State University during the project implementation.



Figure 9. Chain Reaction participant teachers at SALiS laboratory

Kelly's theory and Georgian science teachers' constructs

To get insights into Georgian science teachers' professional attitudes regarding IBSE and their changes we've used Kelly's Personal Construct

Theory (Kelly, 1955). Kelly believed that we try to understand the sense of the word in the way that scientists attempt to understand phenomena by making predictions and developing theories to understand objects and events. Kelly suggested that we are developing a set of personal constructs.

Constructs are bipolar dimensions and represent a lens through which to view our world (Pope and Denicolo, 2001). Therefore, the elicitation of a person's constructs is important in understanding their personal view of their world. In this study we've used the triadic technique for eliciting the teachers' constructs (Epting, et al, 1993). We presented the teachers nine elements (cards) and asked them to choose three elements (cards) - two elements (cards) that they felt were similar to each other but different from a third. After this procedure teachers were engaged in a conversation in which they explained and gave arguments about their choice - why the elected two cards were the same. Here they generated the emergent pole. After teachers were asked to give the arguments why they choose the third element that was different from previous two. In this way they generated the contrast pole. Table 2. Presents the elements (cards) content:

1	The IBSE teacher I would like to be
2	The role of practical in science lessons
3	The ideal IBSE classroom
4	My best science inquiry lesson
5	My best teaching experience
6	My worse science inquiry lesson
7	Myself as an IBSE teacher
8	My worse teaching experience
9	The ideal IBSE lesson

Table 2. 9 Elements (cards)

This study was conducted with 20 Georgian science teachers of the second and third project

year before and after project implementation. After interviews' analysis we are able to state the changes of the teachers IBSE constructs if it is visible.

As the post interviews with the third year teachers aren't finished yet, we present here one example of pre-post constructs of the second year teachers of Chain Reaction (Table 3)

Pre Constructs
Practical work vs. less support from the administration
New Approaches of Teaching vs. lesssupport from the administration
Professional development vs. less support from the administration
Post Constructs
Motivation vs. non motivation
Inquiry Based Learning vs. less possibility for cooperation
Project based learning vs. bad planning

Table 3. Pre-Post Constructs

After analysis is clear that before CPD at Ilia State University and project implementation science teachers addressed their professional development and class activities to school administration. They were waiting support from the administration and it was only way for their success. They stressed the importance of professional development or new approaches of teaching but they were thinking that without administrations' support they weren't able to implement new approaches of teaching and etc. But, after one project year - Chain Reaction CPD at the university and implementation of project activities teachers are discussing about the role of cooperation between colleagues in inquiry-based learning or role of planning in project based learning.

In the interviews teachers reported:

- *Chain Reaction was my best teaching experience*
- *After implementation of EUPRBs I found my own way of teaching*
- *Students became very active; they did measurements in the school corridor and involved the students from the other classes.*

Above discussed constructs illustrate the development of teachers IBSE competences after the implementation of Chain Reaction.

Conclusion

This study underlines the value of the inquiry based CPD programme in general and especially the Chain Reaction CPD programme created and realized at Ilia State University in Georgia.

On the basis of the data analyses after implementation of Chain Reaction project participant Georgian science teachers report about:

- Increased enthusiasm about science teaching and learning
- Increased knowledge of Inquiry Based Science Education (IBSE)
- Improved classroom practice
- More positive attitude to professional development
- Changing thinking about science teaching and learning
- Collaborative working with other colleagues

In their interviews teachers reported about the Chain Reaction students':

- Motivation of science and science education
- Enjoyment of science and science education
- Development of group working skills
- Development of Inquiry based learning skills

From the teachers feedback it is clear that the project implementation is very successful and the project approach helped to strengthen Education for Sustainable Development (ESD) in science education. The trainings that were done in the frame of Chain Reaction promote development of teachers' competencies of IBSE and support applying ESD in science classes successfully. Participating teachers pointed out the positive aspects of the EUPRBs and its structure. Finally, we can conclude that educational reforms and innovation within the school system have to be combined with teacher involvement and improvement of their practice of professional development. This will finally lead to the

enhancement of scientific literacy of more and more students.

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Abstract

Competences are discussed intensively in the context of cross-curricular themes such as Sustainable Development and Education for Sustainable Development (ESD), especially in the light of the United Nations Decade for ESD (2004-2015) and the Global Action Programme on ESD. Recent literature on ESD lists a number of competences for ESD in various fields with the exception of teacher education. In the Austrian research project KOM-BiNE (Competences for ESD in Teacher Education) as part of a large-scale EU project CSCT a competence model for ESD for educators was generated. The KOM-BiNE competence model consists of areas of competences within fields of action. The constituent elements of the competence model are described. As an example for the implementation of ESD competences the nationwide Austrian ECOLOG network (Ecologizing Schools – Education for Sustainable Development) is presented and reflected upon.

Sustainable development

“Humanity stands at a defining moment in history. We are confronted with a perpetuation of disparities between and within nations, a worsening of poverty, hunger, ill health and illiteracy, and the continuing deterioration of the ecosystems on which we depend for our well-being“ (United Nations Conference 1992, 1) – states the preamble to Agenda 21, the programme of action for the 21st century which was adopted by the World Summit for Environment and Development in Rio in 1992 by virtually all countries of the world.

Sustainable development is to solve the above problems: “However, integration of environment and development concerns and greater attention to them will lead to the fulfilment of basic needs, improved living standards for all, better protected and managed ecosystems and a safer, more prosperous future. No nation can achieve this on its own; but together we can - in a global partnership for sustainable development“ (ibid).

As early as 1987, the World Commission for Environment and Development (WCEF) defined the concept of ‘sustainable development‘ (in the Brundtland Report “Our Common Future“) as a “development that meets the needs of the present without compromising the ability of future generations to meet their own needs“ (Hauff 1987, 43). This also implies that environmental conservation is no longer seen as a preferred means of preserving resources for future generations, a tenet held predominantly and unilaterally by the Western world, since “Sustainable development requires us to acknowledge the interdependent relations between people and the natural environment. This interdependence means that no single social, economic, political or environmental objective be pursued to the detriment of others. The environment cannot be protected in a way that leaves half of humanity in poverty. Likewise, there can be no long-term development on this depleted planet“ (UNESCO 2002,

8). A fair and equitable distribution of capital and natural resources, and of living and development opportunities, among all people in the world was the ambitious objective of the world community. Homann (1996) called this function a “regulative idea” – a term he borrowed from Kant (1787/1956). According to Homan, regulative ideas serve as heuristics for reflection. They “steer the searching, research and learning processes in a given direction and direct it to a given focus; in this manner they keep us from poking about in a fog, incoherently and haphazardly. One needs at least an intuitive idea of what one is looking for. Without such pre-concepts, one cannot even formulate a reasonable question or identify a problem (...). Heuristics may help determine the agenda, keep it under a common focus, attract attention to interdependencies in this field, but they cannot determine specific recommendations and proposals.” (Homann 1996, 38f) The non-descriptness of sustainable development as a guiding principle can be perceived as a lack; sustainability can be discounted as an empty formula, even a container term (Eblinghaus & Stickler 1996). Conversely, it may also be seen as an opportunity, even a precondition, to fulfil its function (Brand 1997). The different interpretations to which this guiding principle lends itself give it a broad range of points to tie in with. The term’s lacking precision, its non-descriptness, can make for a highly creative, diverse, yet dynamic field which is oriented to a given direction. In open societies, open notions are likely to meet with an echo, and this is precisely what we are seeing in the current debate on sustainable development. Sustainable development forms a favourable backdrop for reacting to the complex issues which modern-day society is facing in an adequate, manageably complex and not over-simplifying manner (Rauch 2004, 2010).

Education for sustainable development - a socio-political balancing act

Education is perceived as the master key to achieving a sustainable society: “It is widely

agreed that education is the most effective means that society possesses for confronting the challenges of the future...” states UNESCO’s policy report on “Education for a Sustainable Future” (1997, paragraph 38). And in 2000, the World Education Forum in Dakar noted that education constitutes the true basis for sustainable development (UNESCO 2000). In late 2002, the United National Plenary Assembly thus proclaimed the Decade of Education for Sustainable Development (2005 – 2014). To build on achievements of this Decade and create new momentum the UNESCO developed the Global Action Programme on ESD (UNESCO 2014). Education must be geared to social visions and cannot be detached from society. One must be aware of the social dilemma in which ESD operates. Yet as educationalists it is their very task to encourage and empower the next generation to partake in shaping society (Rauch 2015). Whenever facts are complex and controversial, whenever social and economic interests conflict, it is inadequate to “settle the facts without strengthening the persons”, Nagel & Affolter (2004) stated, borrowing a quote from Hartmut von Hentig. It is only individuals with a sufficiently developed self-strength who can act self-confidently on the basis of their own reflection, especially when issues are contradictory and complex (Heinrich et al. 2007).

ESD gives social concerns the appearance of social policy visions, an idea of a better world to which it can be directed. “Education is about hope and therefore about strong and existential feelings of future“, Oelkers (1990, 1) maintained. In this context, Künzli David (2007) mentions three requirements which pedagogical visions for Education for Sustainable Development must meet:

While recognizing social problems, a pedagogical vision must inspire optimism. By orientation to the notion of sustainable development, it is possible to convey complex facts all while giving the feeling that the problems at hand can be tackled. Sustainable development does not

deny problems, but presents them as fundamentally manageable. It can therefore generate and strengthen optimism about the future.

Reality is complex and pluralistic – a pedagogical vision must not propose a one-sided view. Here, the regulative idea concept is an appropriate reference frame for sustainable development. What is sustainable depends on the conditions imposed by where and when stakeholders find themselves and requires a process of negotiation. And: Shifting social visions to the pedagogical level must not be the only measure by which to implement them. Education is only one measure that must go hand with political and social transformations. Education for sustainable development does not aim at changing people's lifestyles, but at "empowering and encouraging them to participate in designing sustainable development and to critically reflect on their own action in this area." (Künzli David 2007, 30)

The role of chemistry for education on sustainability issues

There is no doubt that the field of Chemistry and the industries related to it are in the economic heart of every highly-developed industrial society (Bradley 2005). Industry provides the basic materials necessary for every other type of business. It also defines the basis of energy supply, modern agriculture, and innovative technologies. Unfortunately, many chemical industries around the world have not always been careful in the past. Quite often, they neither concerned themselves with the preservation of natural resources, nor did they give much thought to protecting the environment. Accidents both large and small have significantly contributed to the negative public image of industrial undertakings and Chemistry as a science (Hartings & Fahy 2011). However, a change in attitude has slowly taken place - at least in Western societies (ECCC, 1993). This change goes hand-in-hand with a growing public awareness of both the finite nature of natural resources and the existence of limits which regulate and determine feasible rates of growth (Meadows et al. 2005). Both being careful with

our resources and avoiding damage to our ecology and health has aided in promoting a better image of Chemistry in the past decades. Ever since the 1990s, sustainability and sustainable development have emerged as the core issues of today's chemical industry, its actions and its public image. The report by the European Communities Chemistry Council entitled "Chemistry for a clean world" set the stage in 1993 (ECCC 1993). In the USA, the works of Anastas and Warner (1998) presenting their concept of Green Chemistry began to expand and gain recognition in the mid-1990s. In the early years, a struggle to find a proper name for the concept occurred (Hutzinger 1999). In Anastas and Warner (1998), the idea of a more environmentally friendly and resource-preserving synthesis in Chemistry was expanded to include twelve concrete principles. These principles became the generally accepted guidelines for the contemporary understanding of green, sustainable Chemistry, which has been implemented by both research and industry worldwide. Limited resources and a constantly growing consciousness of the value of environmental protection were both among the driving forces of this movement. But, increasingly stringent legal restrictions for the handling of chemicals and the search for a better self-image for industrial chemistry in Western society also contributed to this development. Today, worldwide initiatives are focusing on a more environmentally responsible form of Chemistry. Examples of this include the ACS Green Chemistry Institute (ACS-GCI) and the European Technology Platform for Sustainable Chemistry (SUSCHEM). The core role of chemistry and chemical industry for sustainable development in modern societies suggests a central role for chemistry education in ESD (Bradley 2005).

Sustainability issues in chemistry education

Adding sustainable development issues to the Chemistry curriculum is not a new idea by any stretch of the imagination. For the last two to three decades, many pupils around the world have been faced in Chemistry education with is-

sues such as keeping water resources clean, dealing with the effects of acid rain, coping with the hole in the ozone layer, and searching for both renewable sources of energy and raw materials. These topics and others have been widely implemented as content in many Chemistry curricula worldwide. Examples include Chemistry in the Community in the US (ACS 2006), the Salters Chemistry curriculum from the UK (Benett & Lubben 2006), chemical industry case studies in Israel (Hofstein & Kesner 2006), or environmentally oriented Chemistry education in Germany (Bader & Blume 1997). In any case, the question of how to deal with issues of sustainable development can take on different appearances and can follow different models. Although they partially overlap and can be integrated in different ways, four different basic models are presented by Burmeister, Rauch & Elks (2012) when it comes to implementing issues of sustainable development into formal Chemistry education:

Model 1: Adopting Green Chemistry principles to the practice of school lab work (i.e. Schwarz, Hugerat & Livneh 2006).

Model 2: Adding sustainability strategies as content in Chemistry education (i.e. Pilot & Bulte 2006).

Model 3: Using controversial sustainability issues for socio-scientific issues which drive Chemistry education (i.e. (Marks & Eilks 2009, Feierabend & Eilks 2011)).

Model 4: Chemistry education as a part of ESD-driven school development (Breiting, Mayer & Mogensen 2005).

Chemistry dramatically influences everything from the life of the individual to society as a whole. Chemistry curricula and chemistry teacher education should more thoroughly reflect not only the importance of education and sustainable development but support the development

of human identity which is interrelated with the environment, both individually and collectively (Zuin 2012) with the goal to allow students actively learn how to shape society.

The KOM-BiNE competency model

The above challenge prompted a large-scale EU project (CSCT) involving 15 teacher training institutions in 8 European countries, in which Austria strongly participated. In the course of this project, a competency model was elaborated for stakeholders in education for sustainable development (Sleurs 2007), as well as an Austrian research project that was financed by the Austrian Federal Ministry of Education, the Arts and Culture for the further development of this model. This model of the competencies which ESD teachers should have acquired in training (KOM-BiNE) is discussed in the following.

The concept was differentiated and concretised (Rauch, Steiner & Streissler 2008, Steiner 2011) based on the interpretation of competence used by the OECD in the DeSeCo (definition and selection of competencies) project (Rychen & Salganik 2003). Franz E. Weinert defined competencies in a dense phrasing as “the cognitive abilities and skills which individuals have or can acquire to solve given problems, as well as the related motivational, volitional and social willingness and skills to apply such solution in variable context successfully and responsibly.” (Weinert 2001a, 27f.)

In order to tackle a complex problem one must not only understand the facts, which in turn presupposes know-how and skills, but also mobilise motivation, feelings and values (Rychen & Salganik 2003). Findings from brain research show that thinking and feeling are inseparably linked (Goncz 2003). Reason exists in and for the entire being, not outside of it. To be successful, educational programmes must therefore also embrace the area of affection (de Haan 2008).

Moreover, competencies do not exist independently of action and context, but are applied by acting in given contexts. Here is where the link

and interaction between individuals and society becomes apparent. When formulating ESD competencies, attention should be paid not only to individual skills and abilities, but also to the setting and context (for teachers e.g. classroom teaching, school community, society).

Weinert (2001b) furthermore pointed out that the skills referred to in recent decades are team or group competencies, i.e. the interplay of individual competencies which enable a group to solve problems jointly. Especially in the context of ESD, cooperation and joint problem solving are of fundamental importance. Having to develop all ESD competencies on one's own is an endeavour that would certainly overtax any individual. As cooperation between all players in the area of ESD is paramount, the KOM-BiNE concept is not based on individuals, but on a group whose members pool their competencies for ESD in specific projects or issues and act as a team. Only by cooperation and targeted competency development within a team is it possible to live up to the complex task presented by ESD.

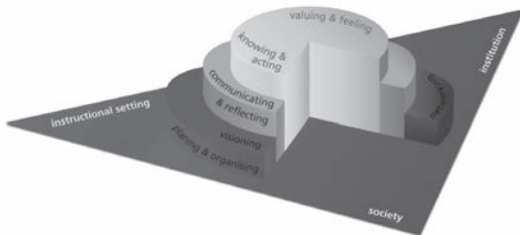


Fig. 1: The KOM-BiNE model (Rauch & Steiner 2013)

Fields of action

Importantly, ESD competencies are competencies for teachers who are presumed to use their competencies in three different social settings. Three different fields of action exist:

- Instruction, i.e. classroom teaching or extra-mural activities;
- Participation in the design of one's own educational institution;
- Reaching out to society, to the institution's closer and wider environment.

In the instructional setting, teachers need com-

petencies to create a climate that is conducive to learning, to arrange for an appropriate learning environment, to tie in with the individual background and abilities of the learners, to select and use appropriate methods, and to create opportunities for active involvement. Within the institutional and societal settings, teachers must look for cooperation partners within and outside of their own institutions. While these are skills teachers generally need, they are paramount in the complex ESD setting which requires a high degree of readiness to cooperate, to solve conflicts and to work in teams. Outside one's own institutions, the ability to set up contacts and co-operation with other educational institutions and to arrange learning opportunities for the learners (e.g. through participation in local agenda 21 processes) is needed. While such competencies are of course desirable in other educational settings as well, they are indispensable for ESD for the reasons stated.

The constituent elements of the competency model are described in detail in the following.

The core area of the model (yellow) consists of more individual aspects which are divided into four fields: "knowing and acting" (subject-matter knowledge, e.g. specific knowledge of ESD, and methodological know-how – ESD didactics and methodologies), "valuing" and "feeling". These areas are closely interrelated.

Knowing

revolves around

- acquiring general knowledge of the contents of sustainable development and of education for sustainable development,
- connecting contents from the different disciplines and from social and cultural contexts and being able to understand interactions and interdependencies,
- becoming aware that knowledge is culture and value driven,
- tackling the uncertainty, preliminaryity and contradictoriness of such knowledge,
- critically challenging knowledge and developing it further in a joint, proactive approach.

Acting

In this area, the players know a repertoire of methods and strategies for how to apply the knowledge and are able to further develop these methods themselves. The aim is to foster the following skills among learners:

- determining and developing values;
- critical thinking and the ability to reflect;
- handling complexity;
- developing future perspectives;
- conflict-solving, communication and team-work;
- problem-solving;
- participation and responsibility; as well as
- independent and self-reliant action.

The teachers focus on action-orientation and contextualisation of the contents. In the formal system of education, they moreover know and use methods of supportive performance evaluation.

Awareness that the acquisition of competencies depends on domains is crucial. Knowledge and skills are acquired and applied in concrete action domains.

Feeling

In the area of feeling, the players try to empathize by e.g. listening, and putting themselves in the place of others (change of perspective). Their attitude is optimistic, they are convinced that sustainable development is viable and that, together, they can make a contribution toward that end. They keep their enthusiasm for ESD alive and try to inspire others to do the same. Instead of mongering fears and frustration by doomsday rhetoric, they encourage learners in their commitment (empowerment).

“Valuing”

ESD is not random, but a fundamentally normative concept. Some models exist which set out quality criteria for ESD (Breiting, Mayer & Mogenssen 2005). “Values” has a multi-layered dimension. Firstly, it relates to values that the players themselves stand and argue for. Secondly, it relates to educational objectives which are to be

promoted or altered, such as a respectful attitude vis-à-vis others, overcoming black-and-white mentalities in the context of sustainable development, etc. Thirdly, it is about values that are lived and which manifest themselves as (unconscious or consciously reflected) attitudes and beliefs, e.g. regarding heterogeneity and diversity as an opportunity and using it as such in the teaching setting. It is also about how values per se are addressed in instruction, such as in debates on values.

Attention is drawn to methods of promoting “ecological judgment competencies”, as postulated by Susanne Bögeholz & Jan Barkmann (2003) and others. By this they understand “the ability to apply factual ecological knowledge systematically to environmentally relevant values to be able to reach a judgment on which decisions are based.” (Bögeholz & Barkmann 2003, 27) or, even beyond that, the “competence to make an ecological judgment ... the ability to reflect on one’s own ethic values as well as a communication repertoire in the search for consensus and fair compromise” (ibid). Teachers themselves should have those competencies; in the competency model, knowing methods to promote and apply these competencies would fall under the heading of “acting” (see above).

Communicating and Reflecting

The middle layer of the competency model consists of “reflecting” and “communicating” and refers to both outwardly directed activities (the outer layer, shown in purple, and to more individual areas (the innermost layer), thereby creating a link between the two.

Communicating is an ability without which all other areas are inconceivable. While communication is a sine qua non for planning, organising, and networking, it is not a matter of course for the more individual areas. Especially in ESD, however, communication is indispensable for:

- values - an appreciative dialogue which respects the opinions of others and takes them seriously,
- feeling – the ability to address highly per-

sonal issues which tend to be given short shrift or completely left aside in teaching, and

- knowing and acting – e.g. sharing one's own experiences, personal knowledge and skills, not wanting to keep them to oneself, making them useful for others according to the "strength concept" (McKeown 2002).

Reflection is important as a means to critically deal with oneself, one's own know-how and skills, values and feelings. Reflecting is equally important with regard to action taken, and is therefore related to the top layer of the KOM-BiNE model (knowledge and skills, values, feeling), as well as to the bottom level (developing visions, planning, organising, networking).

Visioning, Planning and Organising

Sustainable development is an optimistic concept. It is not only about identifying and reacting to the problems of the present, but also about developing visions for the future. How do we want to live sustainably? Or with regard to teaching: What should learning look like in the future? Where are we heading with our teaching, our school in general? What are our goals?

This three-step approach consists of: (1) setting objectives, (2) reflecting on what is possible in a given situation, and (3) translating these ideas into reality.

Networking

Building and maintaining networks within organisations and externally with other persons and institutions is vital for the ESD competence of teachers: With ESD being such an extremely complex field of action, where diverging domains such as the economy, the environment, society and politics must be interlinked, and where broad methodological knowledge is required, it is more or less impossible for teachers to act as individuals on their own. They must set up contacts with others, engage in exchange, work in groups and teams, and cooperate with others and with their institutions. Successful cooperation within their institution as well as with external

persons and institutions thrives on team work, communication skills, conflict management, tolerance, respect of heterogeneity and diversity, etc.

As one requisite competence, ESD teachers must be able to organise and moderate cooperation with non-formal educational institutions, in order to arrange for learning opportunities for pupils in and with extramural institutions. Pupils want to be taken seriously, act constructively in their own environment, and be able to leave an imprint (Posch 1997). From a pedagogical perspective, however, the all-important criterion is not only the implementation of successful activities or visible change in the surrounding world, but selecting opportunities for learning based on their inherent potential for learning (Breiting, Mayer & Mogensen 2005, Künzli-David 2007). For this, teachers need communication as well as planning and organisational skills, so that they can create favourable teaching-learning settings at their own institutions as well as an appropriate framework for cooperation in the social environment.

The Austrian network Ecologizing Schools – Education for Sustainable Development (ECOLOG)

ECOLOG is based upon an action research approach: Schools analyse the ecological, technical, and social conditions of their environment and, on the basis of these results, define objectives, targets, and/or concrete activities and quality criteria, to be implemented and evaluated. Students as well as all the other stakeholders of a school should be involved in a participatory way, and collaboration with authorities, businesses, and other interested parties is encouraged. The measures concern, among others, areas like saving resources (energy, water etc.), reduction of emissions (i.e. waste, traffic), spatial arrangement (from the classroom to the campus), the culture of learning (communication, organisational structure), and health promotion as well

as the opening of the school to the community. All in all, over 500 schools with about 100,000 students are currently part of the network. Many others are reached through the website, teacher in-service-training seminars and newsletters (Rauch & Pfaffenwimmer 2014).

Given the uncertainty of what adequate action in complex situations like networking should be, and the general precariousness of conceptions like education and sustainable development, there is a need to reflect on one's actions. This helps to nurture an ability and readiness for the further development of one's actions in response to the outcome of the reflection process. Competent, professional action in complex situations, hence, requires concomitant learning processes as a *sine qua non*. Inversely: professional learning requires the experience of acting in complex practical situations. From these perspectives, professional action and professional learning coincide in one stream of action. As professional learning happens in practical situations, which, in turn, are seen to require reflection and further development, knowledge and skill development go hand in hand with practical situational development (Altrichter & Posch 2009). Stern et al. (2014) have recently offered reflections on good action research. They argue that good action research pursues worthwhile practical purposes, connects theory with praxis, and is responsive and collaborative.

Within the ECOLOG-schools network the participants write annual reports based upon the methodology of action research. These reports are presented on the website of the network (www.oekolog.at).

Theoretical background of networks in education

According to Castell (2000), networks constitute a new social morphology in society, where dominant functions and processes are increasingly organised around networks. These networks are enhanced through new information technologies that provide the material basis for their expansion throughout the entire social structure. Castells (2000) conceptualises his notion of 'network'

as a highly dynamic, open system consisting of nodes and flows.

In the wake of these general societal trends and structural transformations, networks have also become increasingly attractive in educational systems. In the 1990s, systemic school modernisation processes were launched by policymakers, prompted by the need for reformatory change in the light of the results of international assessments such as the TIMSS and PISA studies. Since proclaiming "school autonomy" a key goal, the central administration in Austria has focused more and more on contextual activities whilst delegating responsibilities to decentralised units (Fullan 2007). Less bureaucratic steering generates a need for alternative ways of coordination (Altrichter, Rauch & Rieß 2010) and intermediate structures (Czerwanski et al. 2002) such as networks are expected to fill a structural gap and take over functions traditionally assigned to the hierarchy. Ideally, networks are conceived as an interface and effective means of pooling competencies and resources (Posch 1995; OECD 2003). As intermediate structures, they manage autonomy and interdependent structures and processes and try to explore new paths in learning and cooperation between individuals and institutions.

Per Dalin's (1999) description of how networks function in education is an important theoretical basis underlying the formation of the ECOLOG network. Accordingly to Per Dalin, networks have four functions. Firstly they have an informative function which becomes visible in the direct exchange of practice and knowledge for teachers and schools, and through the network acting as a bridge between practice and knowledge. A second function is to enhance professionalism. Through networking, opportunities for further learning and competence development are encouraged by the members who themselves establish learning function of the network. Trust is a prerequisite for cooperation within a network and is the basis for the third function - the psychological function which encourages

and strengthens individuals. The fourth function is the political function. The enforceability of educational concerns is based on the motto “together we achieve more” (Rauch 2013).

In order to understand the development of education for sustainable development (ESD) in Austria through networks, social network theories might help. In this respect the authors consider the following aspect of a network to be paramount:

1. Mutual Intention and Goals (Liebermann & Wood 2003)
2. Trust Orientation (McDonald and Klein 2003; McLaughlin et al. 2008)
3. Voluntary Participation (Boos et al. 2000; McLaughlin et al. 2008)
4. Principle of Exchange (Win-Win Relationship) (OECD 2003; McCormick et al. 2011)
5. Steering Platform (Dobischat et al. 2006)
6. Synergy (Schäffter 2006)
7. Learning (Czerwanski et al. 2002; O’Hair & Veugelaers 2005)

Evaluation of the ECOLOG network

Throughout the 19 years of the ECOLOG Programme, a series of evaluations and studies have been written (Rauch & Dulle 2011, Lechner & Rauch 2014, Rauch, Pfaffenwimmer & Dulle 2016, Rauch 2016). These evaluations highlighted a number of factors that have been critical to the success of the network

Communication has proved to be the central element allowing schools to produce a common understanding of ESD. Communication is a key precondition for learning by all members of the school community.

Head teachers play an important role through their “official” support of the project shown through actions such as putting sustainability on the agenda of teachers’ conferences, and by repeated statements of support in the public arena. In addition, heads enhance motivation by recognizing small steps with photos or an information wall for example; maintaining contacts outside the school through public relations and the media and by providing incentives, through for

example, negotiating financial support with the body responsible for maintaining and financing schools.

The backing of the initiative by the Ministry is also seen as a motivating factor. The homepage of the network is an important source of information. Regular in-service training workshops for teachers provide time and space for meetings, bringing people together face-to-face and giving them a sense of identity. Activities in the future will focus on the need to maintain funding, to develop local advisory support further and to develop quality assessment and educational standards. Support should also include a revised political mandate, strengthened quality assurance (agreements on goals that are clear and achievable), early feedback on feasibility, quality monitoring, scientific support, and continuing the resource base (material and non-material incentives).

The openness of the ECOLOG concept allows a wide range of issues to be included and fosters creativity. Its impacts are seen in different areas, such as a change in teaching methods resulting in more project work and social learning, the increased integration of health education through say the availability of healthy snacks, including ecological and social issues in lessons and considering the design of buildings such as the school yard and energy optimization of the school. Participation in ECOLOG results in an enhancement of a schools image and a further development of external relations such as those with the community.

ECOLOG schools that are living out a sustainable culture can influence the environmental consciousness and competencies of pupils in a positive way through for example demonstrating a sustainable use of resources. Approximately one third of the 23 ECOLOG schools that were surveyed in one evaluation noted an increased consciousness and self-reflection by pupils towards sustainability topics including a greater awareness of resources use, eating healthy snacks, and changes in shopping habits. Addressing values and the interconnection of knowledge

are especially important. Having said that, the importance of a school should not be overestimated as it is only one influencing factor among many. Some schools successfully involved parents in sustainability activities and this is another supporting factor. More primary schools more than secondary schools managed this.

On the one hand ECOLOG is an active network due to the personal engagement of individual teachers. On the other hand it is necessary to establish a culture of teamwork to enable the development of a sustainable school culture. This is a challenge for schools.

ECOLOG schools are committed to quality development and assurance. The production of annual reports along the lines of a school development plan caused some difficulties in the beginning. After more than 10 years, however schools have written these reports with greater ease and the ECOLOG annual report is seen as a helpful tool for reflection and planning. ECOLOG supports quality development through the definition of visions and aims, such as the shaping a liveable world and the perception of nature as a whole. Furthermore, ECOLOG offers a broad range of evaluation and reflection methods and as a result contributes to the implementation of legal provisions like the quality management of educational standards (especially in science).

Conclusions and outlook

The ECOLOG programme has been growing continually for many years, being the oldest network supported by the Ministry of Education. One reason for this is that ESD is always connected with current developments in the Austrian education system like quality evaluation and quality assurance. Other factors of success are the support system of the network, which keeps the projects going, as well as an active evaluation culture, which includes action research as well as external, formative evaluations, which provide feedback and confirmation (Rauch & Pfaffenwimmer, 2014).

A challenge is posed by the sustainable anchoring of ECOLOG at a school at the interface of

innovation and as part of the dynamic every-day culture of the school. In relation to regional support systems in the federal states, the respective professional and political contexts play a decisive role. The provision of stable and continuous support, which, at the same time, is flexible enough to dynamically respond to change, both makes high demands on all involved actors and, at the same time, also requires adequate resources.

The creation of spaces for exchange, networking, and reflexion are central elements of the ECOLOG programme, through which it hopes to support the professional development and competences of teachers in the field of ESD.

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Experiments at the Nanoscale for Teachers and Students

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Abstract

In this chapter, we present lab activities which aims to highlight the concepts of nanoscience and nano-materials among students and teachers by a unique points of view. An electrical conductive films made of silver nanoparticles are fabricated, using electrical conductive polymer which acts as a bridge between the particles, this activity describes a simple method for fabricating conductive thin film, compared with the conventional method, which is very complicated and high cost.

In a second part of the lab activity, the students could produce emulsions of liposome structures using phosphatidylcholine as a surfactant, following by minimizing the size of it from micro-scale to nanometer scale (400nm), using simple apparatus called Mini-Extruder, in that way the students could realize the change in solution transparency when the size of the liposomes is reduced.

These experiments are appropriate for teachers, high school and college students.

Introduction

Nanotechnology has become a popular buzzword in science and politics. This key technology is considered not only a major source of innovation in technology, medicine, and other fields, but also one of the main challenges for the 21 century (Matthias, 2008). The ability to create materials, devices, and systems at the nanoscale, create new properties and functions by working at the atomic, molecular, and supramolecular levels (Roco, 2001).

The increasing relevance of nanotechnology and nano-chemistry in chemical education has been pointed out recently (Aiken & Finke, 1999). Moving from the bulk to the nanoscale, the physicochemical properties of materials undergo formidable changes, and noble metals are especially suitable to illustrate such variations.

This chapter offers an opportunity for participants to learn about nanoscale materials. Two dif-

ferent lab activities are presented, in the first one; the students fabricate electrical conductive films based on silver nanoparticles using standard laboratory equipments and procedures (Abu-Much & Hugerat, 2016), it focuses on highlighting the importance of nano-materials in our everyday life, which gives the students the opportunity to explore from one point of view the importance of nanomaterials in technology. The manufacture of thin conductive films is considered very important for various electronic devices; the conventional method is very complicated, with high cost (Campbel & Villarreal, 2012). Nowadays, very simple alternative methods were developed based on metal nanoparticles (Hecht & Hu, 2011) which exhibit easy, rapid processing techniques to fabricate such films. The procedure based on simple reduction of silver ions. To prevent clustering the nanoparticles together and precipitation, conductive polypyrrole, and poly-

diallyldimethyl ammonium chloride (PDAC) were used to stabilize the silver colloid (Valenia, Marccus, Jose & Osvaldo, 2012). Polypyrrole (PPy) is a typical electro-conductive polymer from the class of the unique materials, which combine metallic and semiconductor properties with such polymeric characteristics as flexibility, strength, and elasticity (Herbert, 2002). The conductivity of Polypyrrole is derived from its structure which distinguished by alternating single and double bonds between carbon atoms in the doped polymer backbone. Fig.1 depict the chemical structure of PDAC, and electrical conductive Polypyrrole.

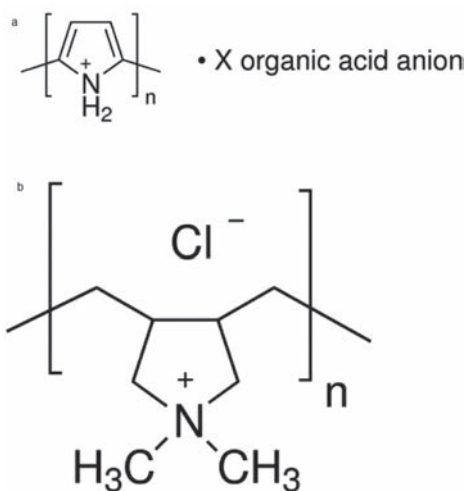


Fig.1 Chemical structure of: a. doped electrical conductive Polypyrrole. b. Poly-diallyldimethyl ammonium chloride (PDAC)

The second part of this chapter presents an experiment in which the students explore the "world" of nanomaterials and nano-systems by producing different emulsions of liposome structures using phosphatidylcholin as a surfactant. Its structure (Figure 2) incorporates choline as a "head" group while two fatty acyl groups are the "tail" groups. It is a major component of biological membranes and can be easily obtained from a variety of readily available sources such as egg yolk or soy beans from which they are physically extracted using hexane.

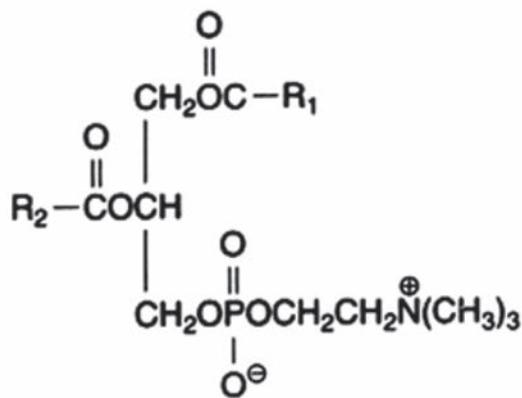


Figure 2: The chemical structure of phosphatidylcholine

At this part of experiment, we expose the students to the science of colloid solutions by a unique point of view (Abu-Much & Hugerat, 2013). Typically emulsion solutions are transparent, that is mean light can usually pass through the solutions, it may have a color but still transparent. Whereas, the transparency of colloid solutions is depend on the size of the structures of the dispersed phase. When we talk about true solution we mean a homogeneous mixture of substances in a molecular scale, so it transmit the light easily, but when the solution has structures of clumps of molecules like colloid solutions it frequently appear turbid.

The different solutions prepared are locked turbid because of the large size of the liposome structures, which is in the micrometer scale; in the second step of this activity, we have fascinated the students when turning these solutions from turbid to more transparency by minimizing the size of the liposome structures using a Mini-Extruder apparatus. Basically this apparatus allows scientists to prepare unilamellar vesicles by extrusion in an efficient, and rapid manner (avantilipids.com). The holder/heating block allows the extrusion of unilamellar vesicles at elevated temperatures, which is critical for the successful production of vesicles from phospholipids with a phase transition temperature above room temperature. Constructed of stainless steel and Teflon, this new design allows rapid clean-

ing of all wetted parts, which reduces the "down-time" between production of vesicles from different lipid species. In our lab activity, we have exploited this simple apparatus in order to minimize the size of the liposome structure by passing it through 400-nm membrane, so the solution becomes more and more transparent and clear as a function of the number of passes.

2. Experimental Details

2.1. Fabricating Electrical Conductive Thin Films

Ag nanoparticles were synthesized by silver salt (AgNO_3) reduction with sodium citrate (Lee & Meisel, 1982), with and without the addition of Polypyrrole that acted as a stabilizer and protected the nanoparticles from agglomeration and clustering together. In addition, silver nanoparticles stabilized by Poly-dimethyl ammonium Chloride (PDAC) were prepared for comparison.

2.1.1 The Preparation of Silver Nanoparticles without Polypyrrole

Two milliliters of trisodium citrate solution in water (1%, 0.034M) were added dropwise to a heated (94-95 °C) solution of AgNO_3 (18 mg in 100 ml of water) while stirring. The mixture was kept heated for 10 min, and then was cooled to room temperature.

2.1.2 Preparation of Silver Nanoparticles Stabilized by Polypyrrole and Poly-dimethyl ammonium Chloride (PDAC)

A number of solutions with different concentrations of Polypyrrole were prepared as follows: Two milliliters of trisodium citrate solution in (1%, 0.034M) were added dropwise to a heated (94-95 °C) solution of AgNO_3 (18 mg in 100 ml of aqueous Polypyrrole solutions of 1%, 0.8%, 0.5%, 0.3%, and 0.1% w/w), while stirring. Each mixture was kept heated for 10 min, and the resulting dark-black solutions were cooled to room temperature. The dark black color is due to polypyrrole that has a black color.

The preparation of silver nanoparticles stabilized by PDAC was performed as follows:

Two milliliters of trisodium citrate solution (1%) was added dropwise to a heated (94-95 °C) solution of AgNO_3 (18 mg in 100 ml of aqueous PDAC solutions (1%, 0.8%, 0.5%, 0.3%, and 0.1%w/w), while stirring. Each mixture was kept heated for 10 min, and the resulting solutions were cooled to room temperature.

2.1.3 Formation of Thin Conductive Films

Thin electrical conductive films made of silver nanoparticles were prepared very simply: the silver colloid solutions were deposited on a microscope glass substrates using regular pipette, creating films of 4cm length and 0.5 cm width, consisting of 12 layers of silver solution. Each layer was prepared by spreading 2 ml of solution on the glass substrate, letting it dry, and then spreading another layer. This process was repeated until the 12 layers were formed.

Digimatic Micrometer-APB-1D was used to measure the resistivity of the dry films.

The measurement of electrical conductivity (σ) was done by using the simple equation:

$$\sigma = 1 / \rho$$

$$\rho = R \cdot A / L$$

Where,

ρ = Resistivity (constant value), [ρ] = Ωcm

R = Film's resistance, [R] = Ω

A = Film's cross-sectional area, [A] = cm^2

L = Film length, [L] = cm

[σ] = $1 / \Omega\text{cm} = \text{S/cm}$

2.2 Producing Different Emulsion of Liposome Structures

Three different emulsion solutions of liposome structures were prepared as follows:

- O/W emulsion (5% soybean oil in water and 1% phosphatidylcholine). The mixture was stirred vigorously using a magnetic stir bar and stirring at room temperature for 1h.
- O/W emulsion (5% soybean oil in water and 1% phosphatidylcholine) with 10mg hydrophilic red dye. The mixture was stirred vigorously us-

ing a magnetic stir bar and stirring at room temperature for 1h.

c. O/W emulsion (5% soybean oil in water and 1% phosphatidylcholine) with 10mg hydrophobic red dye. The mixture was stirred vigorously using a magnetic stir bar and stirring plate at room temperature for 1h.

The three solutions prepared, were then sized by multiple extrusions through a stacked membrane of pore size of 400nm using a medium pressure extruder (Figure 3), This apparatus allows us to minimize the size of liposome structures to colloidal dimensions. The liposome size distribution is considered as a function of the number of passes through the Extruder membrane. A minimum of 11 passes through the Extruder membrane is recommended for most lipids. In that way the students could realize that minimizing the size of aggregate droplets was reflected by getting more transparency solutions. All the solutions were viewed with an optical microscope.



Figure 3: Mini-Extruder Apparatus

3. Results and discussion

3.1 Electrical Conductive Thin films based on Silver Colloids

Three solutions of silver nanoparticles were prepared, the first without adding a polymer, the second with silver nanoparticles stabilized with Polypyrrole and the third with silver nanoparticles stabilized with PDAC. Polymer layers served as a barrier against the attraction between the nanoparticles, resulting in obtaining stable solutions of silver nanoparticles in the case of using PDAC and Polypyrrole.

In the case of the preparation of silver nanoparticles without using a polymer, a pale brown

color solution and mirror like illumination on the walls of the Erlenmeyer flask was obtained and the nanoparticles were held together by strong van der Waals forces, forming agglomerates of increasing size. Yellow-brown solutions were obtained by using PDAC as a stabilizer, while black stable solutions of silver nanoparticles were obtained with Polypyrrole as an electrically conductive stabilizer (Fig.4).

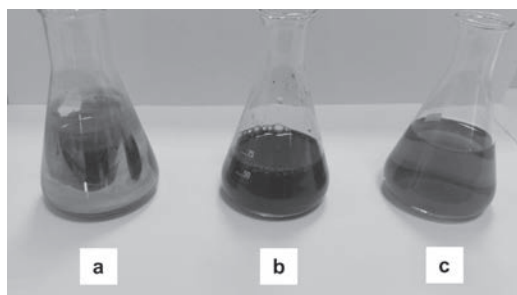


Fig.4. Images of:

- a. silver nanoparticles prepared without a polymer;
- b. silver nanoparticles prepared with Polypyrrole;
- c. silver nanoparticles prepared with PDAC.

UV-Visible spectroscopy is one of the most widely-used techniques for structural characterization of silver nanoparticles. It is quite sensitive to the presence of silver colloids because these nanoparticles exhibit an intense absorption peak due to surface plasmon excitation (Mie, 1908). The absorption band in the 350 nm to 450 nm region is typical for silver nanoparticles. The absorbance of silver colloid solution (stabilized by polypyrrole) was observed by the UV-VIS spectrophotometer as shown in figure 5.

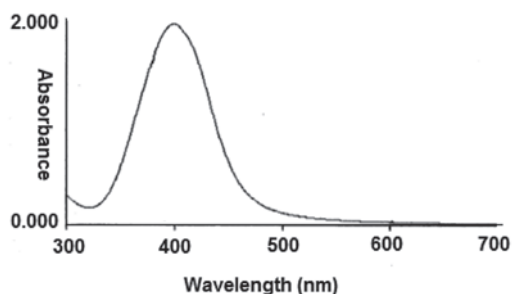


Figure 5: Absorbance Spectrum of Silver Nanoparticles Stabilized with Polypyrrole

The spectrum exhibits a plasmon absorption band at ~ 400 nm, which is characteristic of silver nanoparticles (Lee & Meisel, 1982). Such plasmon bands are unique physical properties of the nanoparticles themselves. When an external electromagnetic field such as light is applied to a metal, the conduction electrons move collectively to screen the perturbed charge distribution that is known as plasma localized near the metal surface.

The basic idea of producing thin electrical conductive films based on silver nanoparticles was very interesting activity for the students and enables them to explore and imagine nano-scale materials and their important applications.

Fig.6 depicts the conductivity values of different films made of silver nanoparticles. Three solutions of silver nanoparticles stabilized by Polypyrrole were compared with three other solutions stabilized with non-conductive PDAC. It can be seen clearly that silver nanoparticles stabilized by PDAC have no conductivity, while stabilization with Polypyrrole makes them retain their conductivity. The Polypyrrole chains act as a conductive "bridge" between the disconnected silver nanoparticles (Shengyu, Shuangxi, Lianxiang & Chun, 2007).

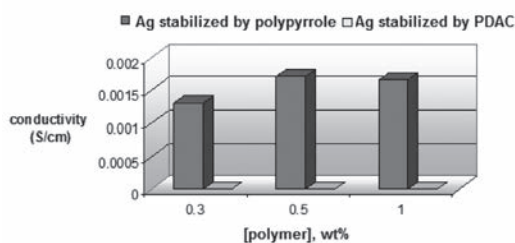


Fig.6. Conductivity values of silver nanoparticles films stabilized with Polypyrrole and PDAC

The purpose of comparing films of silver nanoparticles stabilized by electrical insulator polymer with those stabilized by conductive Polypyrrole was to enable the students explore the behavior mode of the polymers as stabilizers and "bridges" between the electrical conduc-

tive silver nanoparticles. Despite the electrical conductivity of silver nanoparticles, films with PDAC are insulators because of the discontinuities among the nanoparticles while Polypyrrole helps retain the conductivity of silver nanoparticles by acting as a conductive "bridge" between them.

3.2 Emulsions of micro- and Nano-scale Liposome Structures

Figures 7a-c show photographs of samples taken from each of the three solutions prepared. It can be seen clearly that the two samples that were supplemented with either hydrophobic or hydrophilic red dye seemingly look the same, despite the differences in their compositions. The participants reveal the fascinating structures and the way the red dyes "organize" themselves either outside or inside the liposome structures by viewing the images of these solutions with the aid of optical microscope.

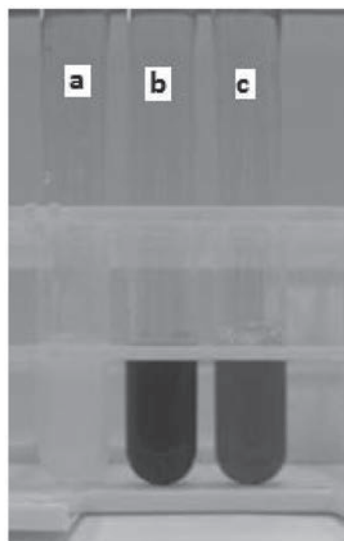


Fig.7. A photograph for the solutions a, b, c, d, comprised of different combinations of oil, water, surfactant and hydrophilic/hydrophobic red dyes as described in the procedures section

The optical microscope images for, a: O/W emulsion without a dye, b: O/W emulsion with a hydrophilic dye, and c: an O/W emulsion containing a hydrophobic dye are presented in Figures 8a, b, and c, respectively.

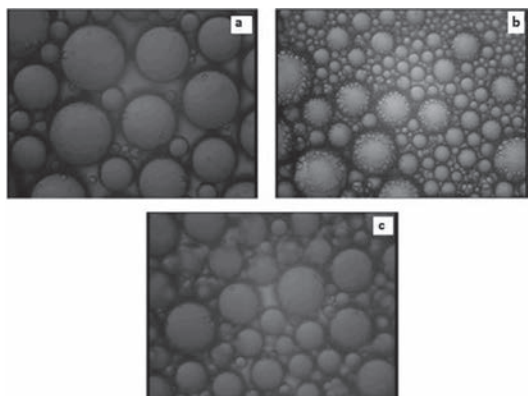


Fig.8. Optical microscope images with a 40 X magnification of O/W emulsions a) without a dye, b) with a hydrophilic dye and c) with a hydrophobic dye.

In the case of the O/W emulsion, we predict the presence of structures that have the hydrophobic interior region surrounded by the hydrophilic continuous water phase.

The results presented in Figure 8 clearly show that non-colored spherical structures were obtained in the O/W emulsion prepared without adding the red dye, while red-colored spherical structures were obtained when the O/W emulsion was supplemented with a hydrophobic dye (Figure 8c). On the contrary, a red-colored continuous aqueous phase containing non-colored spherical structures was obtained when a hydrophilic dye was used in the preparation of the O/W emulsion (Figure 8b). The explanation of these interesting images is related to the structures produced when preparing O/W emulsions. We can conclude that when hydrophobic dye is added, it favors the hydrophobic interior part of the structures comprised of oil phase, while hydrophilic dye favors the hydrophilic continuous phase of the mixture comprised of water phase. In addition, one can clearly observe the reduction of the liposome's size when passed through 400-nm membranes (Figures 9a-b). Generally, extrusion of multilamellar liposomal solutions using membranes with a pore size of more than 200-nm does not produce unilamellar liposomes. Liposomes produced with larger pore membranes will yield a polydisperse solutions of multilamel-

lar liposomes. These facts are reflected in figures 9a-b, we could easily realize that the liposomes are not uniform in size. Moreover, the students could easily realize that the solutions became more transparent despite the increase of the number of liposome structures when it reduced, and by viewing inside these solutions they could detect the relation between the size of it and the solution transparency

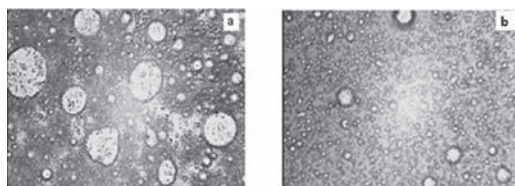


Fig.9. Optical microscope images with a 40 X magnification of O/W emulsions a) with hydrophilic dye, b) with a hydrophilic dye after passing through a stacked membrane of pore size of 400 nm.

4. Educational Component

College Freshmen from the Academic Arab College for Education in Haifa, Israel, who are studying to be science teachers, participated in this lab activity as a part of the course "Chemistry in the Lab". Following the lab activity, the researchers asked the participants to fill in a survey to examine their impressions about the lab activity, their previous knowledge about the topic of nanoparticles and their predictions of the benefits to their students through the implementation of this activity in their classrooms in the future.

An analysis of the survey revealed the following:

1. Regarding previous knowledge about nanoparticles, the majority of the students stated that they had gained basic knowledge through formal education in the previous year in secondary school, and that they had not received any information about new developments in the field of nanoparticles from recent science education journals.
2. The students were asked if they learned about nanoparticles in their classrooms. The majority stated that they had learned about nanoparticles using high-cost materials and apparatuses.
3. They were then asked to describe briefly

whether the experiments presented in this lab activity helped them to understand the process of nanoparticles in a better way. Most of them answered that after the lab activity the concept of nanoparticles became much clearer to them and that they would now be able to explain it clearly in their classroom in the future. In an anecdotal remark one of the students stated that at the beginning of the lab activity she had a very little knowledge on the subject, but that after doing these experiments she knows enough to be able to present it to her students in the future. Most of the participants concluded that the nanoparticle experiments allowed them to visualize what occurs during a process of conductivity using silver nanoparticles. In the same manner, students commented that these low cost experiments were presented in a way that was easy to implement and did not need a complicated science laboratory. Some of them also showed a clear gain in substantive knowledge, by using specific language to explain what occurred in the electrically conductive thin films made of silver nanoparticles.

4. When they were asked about whether they think they would implement this kind of activity in the future when they become science teachers, the students expressed their intentions to carry out some of these activities in their classroom, especially the low cost experiments.

5. The students believe that these activities will enhance the learning process in their classroom in the future, claiming that today most students are visual learners and this kind of activity will motivate and engage them in the learning process of these concepts and will encourage them to do research in this field in the future.

5. Conclusion

Two different lab activities were conducted that aim to highlight the concept of nano-systems and nano-materials. In the first one, different emulsions of liposome structures were prepared; this was followed by reducing the size of it to nanometer scales. In the second part, producing thin

films with electrical conductivity was an interesting idea for highlighting the concept of nano materials among students. The fabrication procedure of silver nanoparticles and the production of electrical conductive films could be considered a very useful teaching model for metal colloids and their applications. We believe that such experiments affect student attitudes to science and can encourage them to perform similar experiments when teaching in the future, and this in turn will lead to a significant change in the way the subject of nano materials is taught in science classes.

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