The Potentials of Nanoscience for the Implementation of an Education for Sustainable Development in Chemistry Class

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Abstract

Education for Sustainable Development (ESD) is an interdisciplinary educational concept affecting the three dimensions economy, ecology and social issues. It is more specifically aiming to enable students 'to constructively and creatively address present and future global challenges and create more sustainable and resilient societies'. The subject chemistry plays an important role in the implementation of this concept in school settings. Especially the topic nanotechnology, as an interdisciplinary research field relating to all three dimensions of sustainability, is particularly suited to support an ESD. Additionally, it provides a lot of controversies as well as opportunities for discussions, because on the one hand the effects of the utilization of nanomaterials in everyday life items have not been sufficiently investigated yet and on the other hand it offers new solutions for the protection of the climate and ensures a more sufficient energy supply.

In order to support a nanotechnology-based ESD and implement it into school settings, a project called 'NanoBiNE' (BNE is the German acronym for ESD), funded by the German Federal Environmental Foundation, was initiated. In this context a project team comprised of scientists from four different universities in northern Germany was formed. Within this contribution, we present the main goals of this project and how they are being implemented into schools, student laboratories as well as teacher trainings.

1. Introduction

In order to face global challenges such as the shortage of resources as well as drinking water supply, or climate change, students need to develop specific competencies to design their future in a self-determined way. An Education for Sustainable Development (ESD) is an educational concept, enabling students to develop these competencies [1] and has therefore already been implemented into school settings in Germany [2]. A suitable content to support competencies in the area of an ESD in chemistry lessons is nanotechnology. Due to its interdisciplinary character, it affects the three dimensions of sustainability: ecology, economy and social issues [3]. To integrate nanotechnology in the context of an ESD, a project called NanoBiNE was developed at four universities in the northern part of Germany.

Following, it is presented why nanotechnology is expedient to promote an ESD and how the NanoBiNE-project is implementing these contents into university and school settings.

2. Nanotechnology in a Context of an ESD

The three dimensions of sustainability are depicted in Figure 1. They are presented in the shape of a triangle, demonstrating both, their interdependencies as well as their equal statuses and importance within the ESD [4].

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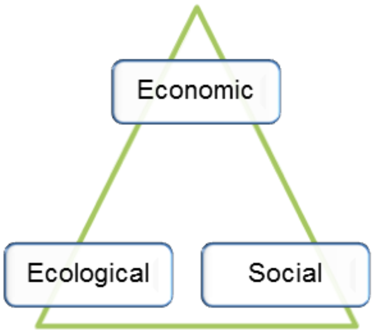

Fig. 1. The three dimensions of sustainability arranged in the shape of a triangle, according to Hauff and Kleine [4].

Nowadays, nanomaterials are becoming increasingly more relevant for the chemical industry. More and more new products containing nanomaterials and possessing novel and improved properties are being developed, such as highly efficient solar cells or more flexible as well as stronger sports equipment. Hence, the global nanotechnology market was estimated at 15.9 billion USD in 2012 and is predicted to reach 37.3 billion USD by 2017 [5]. Consequently, more jobs in this sector are being created, fostering the economic growth.
Due to their special chemical and physical properties, artificially synthesized nanoparticles can be both beneficial as well as detrimental for the environment. While on the one hand, 'nanotechnological proceedings and applications substantially contribute to the protection of the environment and climate, since resources, energy, as well as water can be saved and greenhouse gases as well as problematic waste can be reduced' [3]; on the other hand, nanoparticles find their pathways into the environment through soil, air and water. However, the potentially risky effects are not yet fully investigated. These uncertainties need to be discussed and carefully considered on an industrial, scientifical and personal level.
Not only the potential risks for the environment are unclear, also the effects on the human body are not sufficiently investigated yet. There are different ways in which nanoparticles can enter the body; through the gastro-intestinal system, the lungs, and the skin. If the skin is healthy and undamaged it is normally a safe barrier against the intrusion of nanoparticles. The same is true for the gastro-intestinal system. The lungs, however, with their enormous surface area and their constant interaction with the environment, are the main point of entry for nanoparticles into the human body. Studies have shown that nanoparticles were able to cross into the bloodstream of laboratory animals via the lungs and cause reactions inside the bronchi and alveoli [6]. However, applying nanoparticles to certain items can have social benefits as well, *e.g.* by coating surgical instruments with silver nanoparticles, making them more antibacterial.

3. Goals and Contents of the NanoBiNE-project

In order to take advantage of the above described potential, the NanoBiNE-project was developed to support the implementation of the ESD's competencies into school settings and beyond. The main goals of this project are that students

- develop answers and solution strategies for ecological, economic and social problems in a globalized world, on a local as well as a global level,
- acquire skills and competencies to responsibly design their future,
- utilize the interdisciplinary character of nanotechnology to consider an issue from various perspectives,
- focus on participatory learning while promoting citizenship skills through an ethics- and values-driven approach, and
- are being inspired to a life-long learning, integrating formal and non-formal education [7].

The NanoBiNE-project consists of four educational components as shown in figure 2.

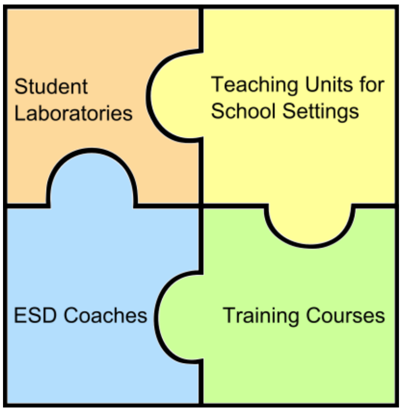

Fig. 2. Four educational components of the NanoBiNE-project.

As a first step, student laboratories at two universities are being established. The courses offered by these laboratories are designed to promote nanotechnological contents as well as competencies of an ESD.
On the basis of these student laboratories, teaching units for school settings are being developed in collaboration with teachers and tested in schools. Based on the teachers input during the laboratories, adjustments will be made to optimize the teaching unit in terms of a participatory action research. A close cooperation between teachers and researchers is therefore indispensable in order to combine ESD competencies with curricula competencies.
For students to internalize the competencies necessary for the creation of a self-determined future, they need to act responsibly and sustainably in every aspect of their lives. Therefore, it is insufficient just to hear about and practice sustainability during lessons; the students need to put the ESD competencies into practice in their daily routine. One of the goals to support the ideas of an ESD, is to educate motivated students and establish them as ESD Coaches at schools. With the help of their teachers they will develop and promote projects manifesting a critical thinking in hopefully every aspect of their own and their classmates' lives.
Finally, it is very important to offer training courses to share experiences and improvements and new developments with teachers regarding the different projects. Additionally, these training courses are a necessity in order to continually attract teachers towards the project.

3.1 Student Laboratories

The following section of this contribution will focus on student laboratories. All of the courses are basically structured in a similar manner. They all start with an introductory seminar in which students first learn about nanotechnology in general. Questions such as "What is the spatial dimension of nanoparticles?", "What make nanomaterials special and what are their properties?" and "Where do we encounter nanoparticles in our everyday lives?" are answered during this phase.
The introduction is followed by an experimental phase, in which the students synthesize different nanoparticles in different manners (*e.g.* through precipitation reactions or calcination) and investigate their properties. One important aspect is the investigation of the toxicity of nanoparticles by examining the effect of different nanoparticles on the alcoholic fermentation.
Moreover, after the experimental phase, the students perform a simulation game in order to enhance their ESD's competencies by

- stimulating them to shape the future actively,
- allowing them to experience global scale problems in a local setting,
- imparting a differentiated knowledge, in order to call different points of view to their attention,
- taking different perspectives into account when making decisions, and
- emphasizing the interdisciplinary nature of nanomaterials as well as uncertainties and opportunities [8].

During the simulation game the students have to decide whether or not nanomaterials should be applied to everyday items, such as titanium dioxide nanoparticles in sunscreen or silver nanoparticles in washing machines. Within their argumentation, they should use their newly acquired knowledge and take different perspectives into account when analyzing the situation from as many points of view as possible. Analyzing a situation from various perspectives is one of the main goals of the shaping

competence concept according to de Haan [9]. This concept, developed to specify and classify the ESD's goals, is the most popular concept in Germany for the promotion of an ESD.
Finally, the students first reflect the simulation game on the basis of specifically designed key questions and later the course in general. For this purpose, they first reflect the outcome of the discussion and the role they played within the simulation game. Questions such as "Are you satisfied with the solution" or "Did you feel comfortable in your role?" are being asked and discussed in order to review the simulation game on a metaplane. Additionally, in order to improve the course, the opinions of the participating students regarding the course design and the actual content are being collected.
The following table summarizes the general structure of the student laboratories as well as the corresponding learning objectives:

Phase	**Learning Objectives**
Introductory seminar	• introducing students to the nanodimension • discussing the properties and applications of nanomaterials
Experimental phase	• synthesizing nanoparticles • investigating nanomaterial's properties (especially their toxicity)
Simulation game	• promoting evaluation as well as discussion skills • taking different perspectives into account
Reflection	• reflecting the simulation game on a metaplane • assessing the laboratory course

4. Outlook

As shown, nanotechnology works perfectly as a catalyst for the implementation of an ESD in chemistry classes. By establishing the NanoBiNE-project, this potential is being utilized to create a more sustainable education in northern Germany.
Accompanying research to the project's implementation should guarantee a constant (re-)evaluation and optimization of the project. It is therefore crucial, that students fill out a developed questionnaire and that the teachers' perspectives are investigated with the help of structured guideline interviews.
Moreover, after a successful implementation in Germany, an internationalization of this project is planned to supply valuable suggestions for an ESD worldwide. This could take place through international cooperations as well as an increased involvement at conferences.

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