'NANO' – An Attractive Dimension for School Chemistry Education

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Abstract

While nanotechnology is currently a key subject of intensive research, only a few aspects have yet been didactically conceptualized and considered for chemistry education. The results of several studies[1] related to students' specific knowledge on 'nano' stress that this topic has hardly found its way into german schools. On the one hand, the data reveals that students perceive and even reflect 'nano' in their everyday life, whereas on the other hand a more detailed subject-matter related knowledge (e.g. correct spatial dimensions) can rarely be given. Furthermore, several uncertainties can be observed in other (competence) areas, as, for example, locating applications of nanotechnology in specific domains, evaluating its precise impact on their day-to-day lives and assessing these developments in a well-founded manner. All these provide students with significant challenges. For this purpose, this contribution aims at presenting a dedicated chemistry class project on nanotechnology during which the participants can exploit the spatial (nano)dimensions, the synthesis, properties and applications of nanomaterials with several easy and illustrative (model) experiments.[2][3][4] The latter include for example the isolation and identification of nanomaterials from everyday objects, such as titanium dioxide (TiO_2) from sunscreen or toothpaste, with a focus on the properties and applications of these obtained nanoparticles, such as photocatalytic activity or superhydrophilicity.

1. Introduction

Combining the 'classic' natural sciences of biology, chemistry and physics, nanotechnology is considered a key technology of the 21st century along with artificial intelligence and genetic engineering[6]. Alongside many highly specialized applications in technical domains (*e.g.* EUV lithography), a wide variety of nanotechnologically improved products such as sun screen, tooth paste, Smarties or chewing gums can also be found in our daily lives.

Nanotechnology deals with particles und structures between 0,1 and several hundred nanometers. The altered and fascinating properties of nanoscaled materials are essentially based on a steep increase of the surface area to volume ratio in comparison to the respective bulk materials. Therefore, nanomaterials show an increased reactivity and chemical and physical properties can be enhanced or changed completely. For example, zinc oxide only exhibits a bright yellow fluorescence at a specific nanoscaled particle size; titanium dioxide (which is used as a white pigment) turns transparent within these dimensions.[5]

According to various opinions, nanotechnology already seems to be of great importance for science, industry and everyday life and will become even more important in the future[6][7]. However, regardless of its importance, no detailed focus was placed on the conceptualization of nanotechnology for teaching chemistry in K-12 (Germany) so far. An explorative study[1] with pupils at different ages (n = 100) concerning the subject-related knowledge of nanotechnology stresses these findings. While many pupils are familiar with the term 'nano' (due to its frequent utilization in the media), many misconceptions and significant uncertainties regarding the spatial dimensions of nano are common.

Furthermore, only a few students are able to give fields of application, specific products outside technical domains or assess the impact or significance of nanotechnology for society and their day to day live. However, a vast majority (87 %) is interested to learn more to cover this topic in school chemistry education. Therefore, this contribution presents a chemistry class project on nanotechnology.

2. Nano Chemistry Class Project

The present course design comprises (1) an everyday life relevant introduction to the theory behind nanoscience focusing on the properties, (natural) occurrence, and production as well as the spatial dimensions of nanomaterials. Further, it consists of (2) a laboratory course with six experiments concerning the production and properties of titanium dioxide nanoparticles and (3) a WebQuest focusing in particular on the responsible use and the management of several nanomaterials. The stated purpose is to provide a theoretical overview and a practical approach to this complex subject to the students.

2.1 Introductory Seminar

By showing examples of impressive and everyday life applications, such as lotus effect, 'shark skin' riblet surfaces, sun screen, the introductory seminar covers basic concepts of nanoscience. Special emphasis lies on an accurate representation of the spatial dimensions and the so-called surface-to-volume ratio, which students develop by themselves through a simple model experiment. In this, the continuous division of a cube into nanoscale particles first helps the students to approach the nanodimension mathematically. Second, the increase in the total surface area of all the cubes can be derived by simple mathematic operations (Fig. 1). By offering structured assistance, students develop a general formula that describes the correlation between total surface area and particle size (or degree of dispersion respectively) and thereby explain and clarify the coherence between surface area and volume.

Figure 1: Simple model experiment for a mathematic approach to the nanodimension by the continuous division of a cube.[3]

2.2 Laboratory Course

The laboratory course comprises six simple and safe experiments with titanium dioxide nanoparticles, which can be carried out in group work supported by a laboratory script. The first section focuses on the isolation of this nanomaterial from everyday products and is followed by a simple wet chemical analysis. On this basis, the properties and applications of titanium dioxide nanoparticles are investigated and analyzed.

2.2.1 Isolation and Detection of Titanium Dioxide

a) In a porcelain crucible 6 g of sun screen (alternatively: Smarties, tooth paste, chewing gum) are dried overnight at 120 °C in a (drying) oven. Residual organic species can finally be removed by calcination with a gas burner until TiO_2 is obtained as a dry white solid (Fig. 2 a-c).

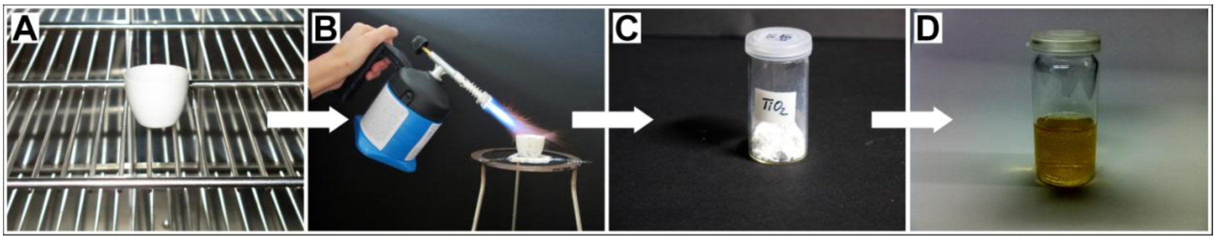

Figure 2: Isolation (a-c) and detection (d) of TiO_2 from sun screen.

b) In order to detect TiO_2, a spatula tip of the product is mixed with five equivalents of potassium hydrogen sulfate in a porcelain crucible and heated until a clear, transparent melt is obtained and white sulfur trioxide vapor rises. As soon as the melt has cooled down, it is brought to a boil in one equivalent of diluted sulfuric acid until the melt dissolves. Finally, the solution is filtered into one test tube where a 3 % hydrogen peroxide solution is added to the filtrate until the presence of TiO_2 is yielded as yellow-orange colored titanium peroxide sulfate (Fig. 2 d), according to the following equations:
$TiO_2 + 2\ KHSO_4 \rightarrow TiO(SO_4) + K_2SO_4 + H_2O$
$TiO(SO_4) + H_2O_2 \rightarrow [TiO\text{-}O]SO_4 + H_2O$

2.2.2 Properties and Applications of Nanomaterials

Titanium dioxide nanoparticles possess several interesting properties resulting in many opportunities and different applications in a wide variety of technological fields. The following experiment illustrates the photocatalytic activity of TiO_2 on the example of the decomposition of methylene blue and includes a comprehensible model suited for school chemistry education.

Photocatalytic Activity of Titanium Dioxide Nanoparticles

60 mL of water are colored with a few drops of methylene blue (c = 0,05 mol/L), stirred and then distributed into three beakers (V = 25 mL). Additionally, 0,3 g of TiO_2 nanoparticles obtained from the first experiment are added into two of the beakers (samples 2 and 3). Prior to the treatment of the solutions with UV radiation, sample 2 is covered with a porcelain lid (Fig. 3).

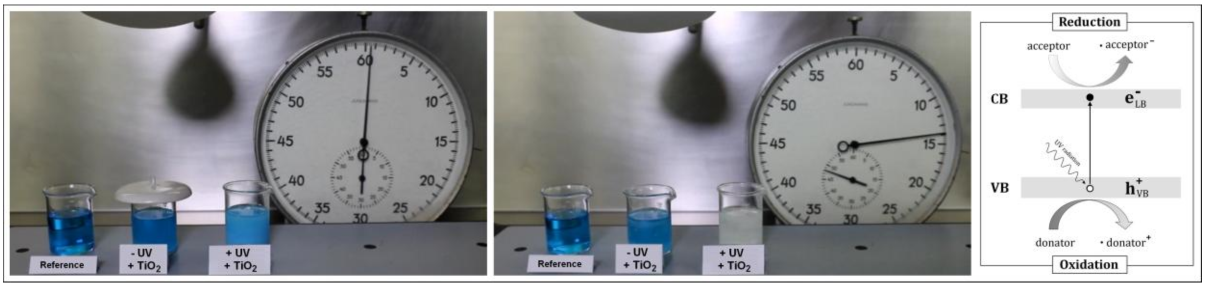

Figure 3: Experimental setup at the beginning (left) and after 15 minutes of UV radiation (center). A model for the explanation of the respective reaction mechanism for school chemistry education is shown on the right.

Degradation of methylene blue occurs due to the photocatalytic activity of TiO_2 nanoparticles. Figure 3 c) illustrates the formation of several radical species under the presence of TiO_2 and UV radiation. An ongoing exposition subsequently results in a complete decomposition of methylene blue into carbon dioxide and water. It can be concluded from the experimental setup that both components are essential for this photocatalytic process.

During this process, electrons are promoted from the valence band (VB) into the conduction band (CB) by means of UV radiation, thus creating so-called electron-hole pairs (excitons), which consist of electrons in the conduction band and electron deficient areas (holes) in the valence band. In a simplified manner, these free charge carriers react in redox reactions at the particle surface with adsorbed molecules such as water. The generated radical species decompose the dye methylene blue explaining the decoloration of the solution. A more detailed description of possible degradation pathways of organic substances by means of photocatalysis can be found in various textbooks.[8]

2.3 WebQuest

The third section combines the previous findings and applications and aims to reflect the use of nanotechnology and nanomaterials in social contexts and to assess potential hazards for humans, animals and the environment. The use of nanomaterials offers an interesting context and a controversial discussion concerning the risks and benefits of new technologies that can be made subject of discussion in chemistry class. In an example, four materials (titanium dioxide, carbon nanotubes, silver, silica) were chosen, each providing a variety of applications on the one hand but a partially unexplained risk potential on the other hand. Unfortunately, this or other comparable debates are not appropriately reflected in current schoolbooks yet, so online resources can be a good alternative to classical (pen & paper) teaching materials. Hereby, an enormous pool of high quality and still not interpreted online resources could be used, particularly in the case of up-to-date issues like nanotechnology. Therefore, it seems reasonable to structure this inquiry as a WebQuest.
In brief terms, a WebQuest describes a method where advantage is taken of the internets' potential for a structured inquiry in class.[9] Here, the preselection of material is a crucial aspect to avoid both inappropriate material and loss of time during data search. This can be done by means of predefined hyperlinks. In addition to the selection of online resources, the students receive support to structure their task: a systematic assessment and the analysis of the responsible use of nanotechnology. Fig. 4 summarizes the four controversies and shows a screenshot of the WebQuest.

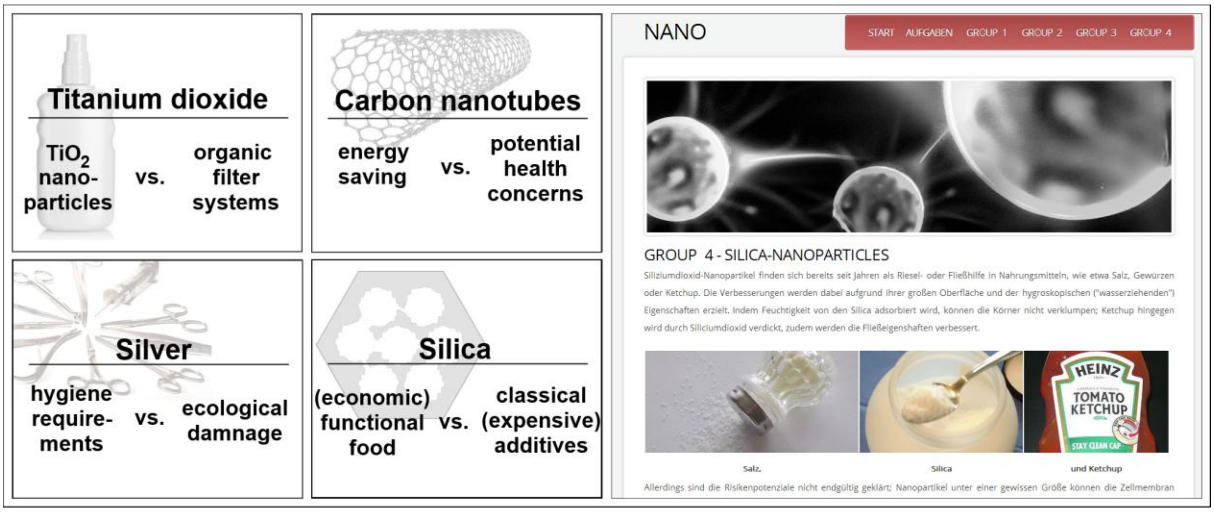

Figure 4: Overview of the discussed controversies (left) and screenshot of the WebQuest (right).

3. Experiences and Outlook

In this contribution, a school chemistry project on the topic of nanomaterials involving various materials such as titanium dioxide has been presented. The evaluation of the presented teaching unit showed a significant increase of subject related knowledge. With regard to the content knowledge, the students were able to reproduce and explain many technical terms, contents or concepts. A more detailed understanding of the spatial dimensions and the surface-to-volume ratio of nanomaterials became apparent, exceeding the simple indication of the numerical value '10^{-9} m'. Furthermore - especially in connection with the experiments which have been described as 'impressive', 'strongly related to our everyday life' and 'very illustrative' - the students recognized the impact of nanotechnology on society and their own lives in a new way or even for the first time. In particular due to the WebQuest, the students' assessment of nanotechnology, its significance and potential risks were often based on knowledge and critical reflection.

In summary, school projects provide an easy way to implement a current and important matter into school chemistry education with the help of cheap and safe experiments strongly related to our daytoday lives. Furthermore, various other nanomaterials – zinc oxide, silver, silica, silicones – are many excellent alternatives to titanium dioxide and enable further experiments, such as a simple synthesis. Finally, the results and the experiences collected in this project reflect the high student motivation and their learning progress which again highlights the interest of the participants in this exciting field.

References

[1] T. Wilke, T. Waitz, in *New Perspectives in Science Education: Conference Proceedings* (Eds: Pixel), University Press 2012.

[2] T. Wilke, B. Niepötter, T. Waitz, in *Pixel (ed.) 2013 – New Perspectives in Science Education* 57 - 61.

[3] T. Wilke, S. Gerke, T. Waitz, *MINTZirkel* 2013, *2 (3)*, 8.

[4] T. Wilke, S. Haffer, M. Tiemann, T. Waitz, *Chemkon* 2012 *(19)*, 67.

[5] T. Wilke, K. Wolf, A. Steinkuhle, T. Waitz, *Praxis der Naturwissenschaften Chemie (in press)*.

[6] J. Bradley, *The Recession's Impact on Nanotechnology*, Lux Research 2010.

[7] M. C. Roco, *Nat Biotechnol* 2003, *21 (10)*, 1247.

[8] D. Wöhrle, M. W. Tausch, W.-D. Stohrer, *Photochemie: Konzepte, Methoden, Experimente*, 2010th ed., Wiley-VCH, Weinheim 2010.

[9] B. Dodge, *Some Thoughts About WebQuests*, San Diego, http://webquest.sdsu.edu/about_webquests.html 1995.