From Sunscreen to Solar Cells - A Science Outreach Project Connecting School and University

Johanna Schakowske [1], Christian Jooß [2], Kay Langemeier [2], Thomas Waitz [1]
[1] Department of Chemistry Didactics, Georg-August-University Göttingen [2] Institute of Material Physics, Georg-August-University Göttingen (Germany)
johanna.schakowske@stud.uni-goettingen.de, *jooss@ump.gwdg.de*, *klangemeier@ump.gwdg.de*, *twaitz@gwdg.de*

Abstract

Photocatalytic reactions play an important role in science and technology as well as in everyday life, e.g. for the decomposition of harmful organic substances, fabrication of self-cleaning glasses or water-splitting for a sustainable energy generation. The Collaborative Research Centre 1073 (CRC) 'Atomic Scale Control of Energy Conversion' at the University of Göttingen deals with these topics to improve the basics of a sustainable energy future, to develop the possibilities for a more effective use of energy and an improved understanding of the elementary steps of energy conversion in materials. Since conversion efficiencies in solar cells, batteries or photocatalysts are still far below the possible thermodynamic limits [1], significant improvement requires fundamental research on new material systems which allow the control of dissipation channels. In order to give high school students insights into this field of research, we developed a teaching concept for chemistry school education. The concept, 'From Sunscreen to Solar Cells', includes hands-on experiments with TiO_2 or ZnO isolated from suncreen as well as teaching materials referring to the topic 'Photocatalytic Water Splitting'. The Model of Educational Reconstruction from Kattmann et al. (1997) was applied as the theoretical framework for the development of the concept and includes the analysis of content structure, perspectives of the learners and the development and evaluation of teaching and learning environments [2]. A close cooperation with teachers and a connection to the curriculum is implemented in order to ensure the sustainability of the concept.

1. Background of the Project

As a basis for sustainable energy supply a progress in understanding the energy conversion in complex materials is required which is the focus of the research work of the Collaborative Research Center (CRC) 1073 'Atomic Scale Control of Energy Conversion' at the Georg-August-University of Göttingen. The CRC aims at an improved understanding of the processes involved in the energy conversion and the associated energy losses in materials at the atomic scale. Based on this, controlling these aspects is intended. The goal of this research is to improve the materials' efficiency of energy storage and energy conversion materials for applications like batteries, solar cells or photocatalysts.

The CRC 1073 has been funded by the German Research Foundation since October 2013 and consists of 28 scientists from the Department of Physics and the Faculty of Chemistry at the Georg-August-University, the Max Planck Institute for Biophysical Chemistry in Göttingen and the Clausthal University of Technology.

Another aim of the CRC is the public outreach in order to disseminate the research program and the everyday life of scientists to the public. In this context, these activities partially focuses on the improvement of the communication and interaction between schools and scientific research. For this reason concepts linking current research and high school teaching need to be developed, so that students notice the relevance of scientific issues for society on the one hand and also get motivated for a scientific study on the other hand [1]. Since the research of CRC 1073 includes many different projects and is therefore very complex, this contribution can only exemplarily display an extract of the cooperation between high schools and the university.

2. Concept of Public Outreach Connecting High Schools and CRC 1073

To develop a fundamental concept for the public outreach in schools (how to transfer the topics of CRC into schools), aspects of the Model of the Educational Reconstruction were used. This means that the theoretical understanding of a scientific topic is related to the understanding and misconceptions of students in this area in order to develop a teaching subject [2]. According to the principles of the Educational Reconstruction a model (University@School) was derived (depicted in Figure 1), illustrating how a connection between schools and CRC can be realized by a public outreach program. The project aims at the development of a learning opportunity with experiments and teaching materials, which should work as both - a sustainable and scientific introduction. For the design of this type of teaching materials various aspects, which play an essential role for the work of both involved groups (school and CRC), have to be taken into account. With respect to the CRC, these include for example subject specific theories, applied research methods and the current research interest. For the school curricula, standards that comprise competences like content specific knowledge, knowledge acquiring and communication have to be considered. Further aspects such as interdisciplinary and developing innovative teaching methods are also essential for the creation of teaching materials intended for a sustainable implementation in high school education.

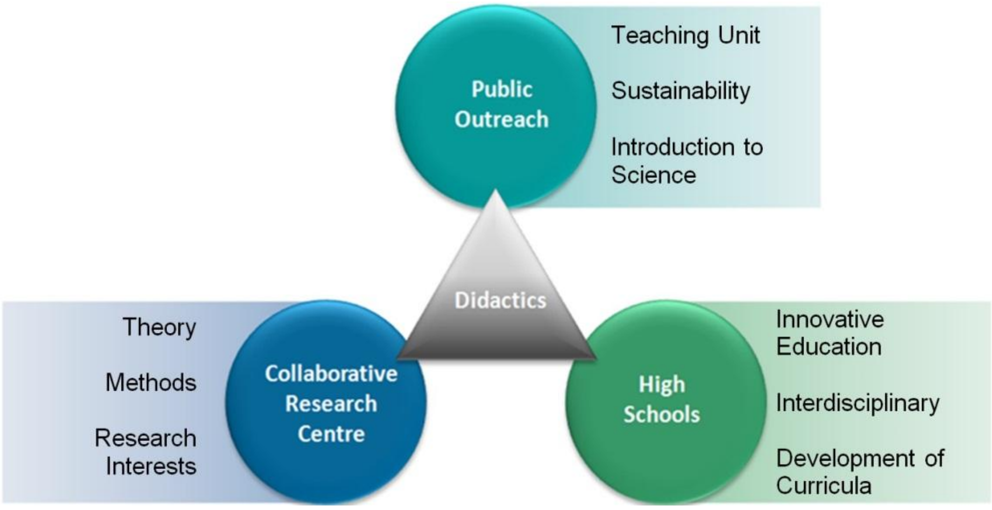

Fig. 1: The Concept of Public Outreach (University@School) shows how a collaborative research center and high schools can be connected by means of a public outreach project. It also shows the interaction of CRC, high schools and public outreach within different areas.

Taking all these considerations into account, the teaching unit for high schools ‘From Sunscreen to Solar Cells’ was designed, comprising approximately two 90-minute lessons with both practical and theoretical parts. This teaching unit addresses the upper secondary level and experiments as well as teaching materials were developed accordingly. To the aspects of ‘sustainable energy supply’, an immediate reference to the CRCs working fields (theories and methods) is also given.

For example, in the first experiment (see below) titanium dioxide (TiO_2) nanoparticles are isolated by calcination of sunscreen. Before they are analyzed by the students in a wet chemistry experiment, the students are introduced to various modern characterization techniques such as XRD, TEM and SEM; thus, the students receive an insight into typical research methods (2nd experiment).

By means of further experiments, the photocatalytic properties of TiO_2 are investigated (3rd experiment). With TiO_2 as an example of a photocatalyst, the relevant processes involved in a photocatalytic reaction can be easily determined. Based on the example of ‘water splitting using TiO_2’ a connection to sustainable energy supply and thus to the CRC is possible. Within the processes of photocatalytic water splitting, ternary metal oxides are investigated by the research group of Prof. Jooß.

Using everyday materials, students can build a Grätzel cell with the isolated TiO_2 particles in a simple way (4th experiment), thus introducing them to the conversion of energy in solar cells. In collaboration with the research department, the learning groups have the opportunity to get an overview of the laboratories and the everyday work of scientists. Additionally, videos demonstrate the work of various CRC laboratories and the research of different scientists in a simplified way. The distribution of the videos by different video portals also provides insight in the field of research of the CRC to the public. The teaching unit intends to demonstrate the relevance of chemistry and physics in everyday life as well as the impact of current research on sustainable energy supply.

3. Selected Experiments and Work Materials

In the following chapter, a brief selection of student experiments for high school lessons is presented.

3.1 Isolation and Identification of Titanium Dioxide Nanoparticles from Sunscreen

This experiment illustrates how TiO_2 nanoparticles can be obtained in a simple way. For this purpose, sunscreen is first dried and then calcinated using a gas burner. Afterwards, the product (TiO_2) can be digested with potassium hydrogen sulphate and detected with H_2O_2 yielding a yellow-orange color [3].

Learning objectives: properties of organic / inorganic materials, method of acid digestion, detection of TiO_2

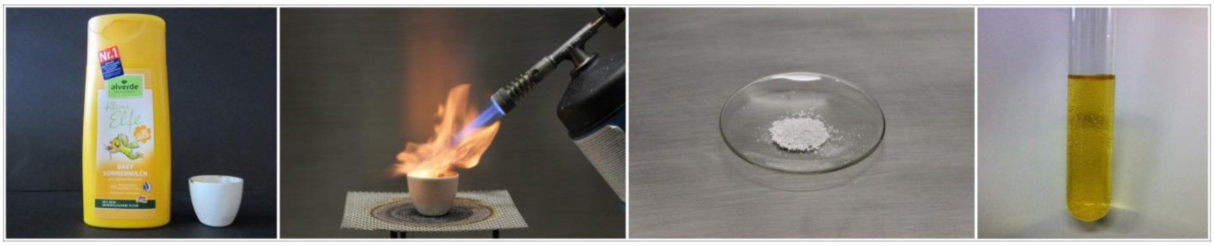

Fig. 2: Sunscreen before and during the combustion and the acid digestion.

3.2 Characterization of TiO_2 Nanoparticles by XRD and Electron Microscopic Methods

The TiO_2 nanoparticles are analyzed in cooperation with partners of the CRC X-ray crystallography and electron microscopy. Students prepare appropriate samples and learn what kind of information can be obtained from diffraction patterns (modification, crystallite size, etc.).

Learning objectives: Design and function of SEM and XRD, Scherrer formula, authentic everyday research

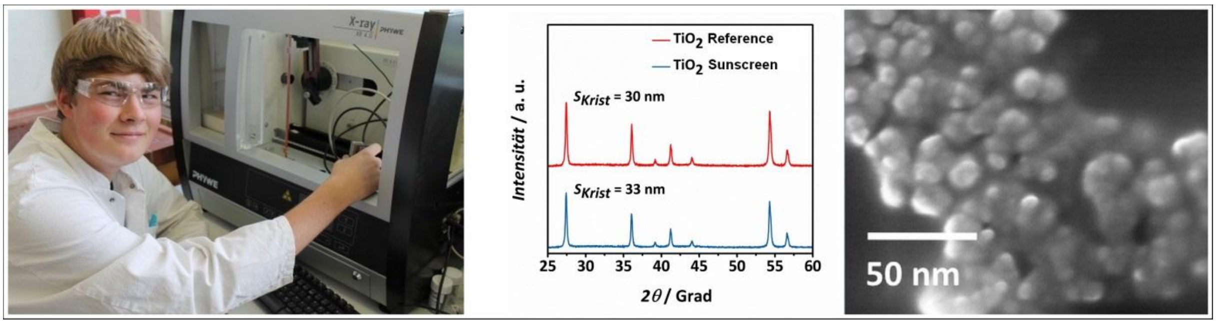

Fig. 3: Student working on a XRD, XRD and SEM image of TiO_2 particles of sunscreen.

3.3 Photocatalytic Decoloration by Titanium Dioxide Nanoparticles

This experiment illustrates the photocatalytic activity of TiO_2 in the presence of UV light. Since this technique is also used in self-cleaning facades and in the purification of water, different fields of application can be highlighted. In this test, TiO_2 is added to beetroot juice and irradiated with UV light, wherein the juice loses its red color [3, 4]. In order to examine the various related variables (UV light, TiO_2), four different samples were observed at the same time. Sample 1 contains juice irradiated with UV light, sample 2 contains juice and TiO_2 and is also irradiated with UV light. Samples 3 and 4 are not treated with ultraviolet light, whereas 3 contains juice and 4 contains juice and TiO_2 (Fig. 4).
Learning objectives: semiconductor, photocatalysis, free radical reactions.

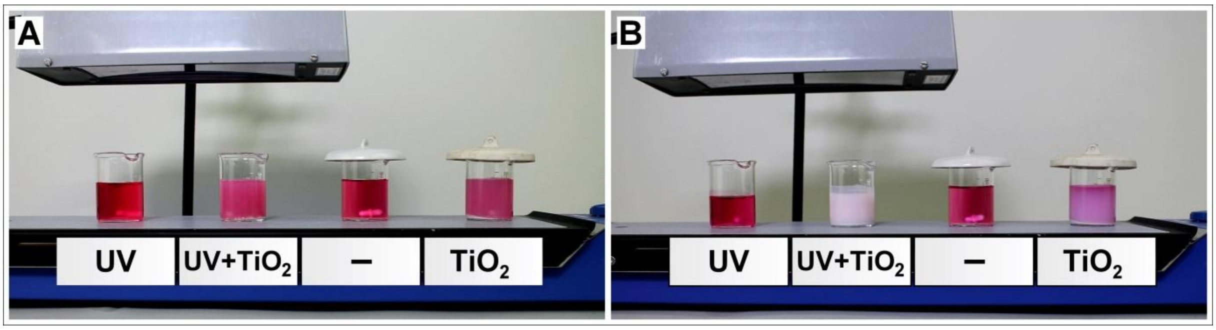

Fig. 4: The four samples at the beginning of the experiment (A) and after 2 hours (B).

3.4 Construction of a Solar Cell from Readily Available Materials

By using everyday materials (vinegar essence, elderberry juice, silver lacquer, pencil and scotch tape) a Grätzel cell can be built by students. First of all, a TiO_2-vinegar paste is applied to the non-conductive side of the FTO-glass and then soaked with elderberry juice. A second FTO-glass is coated lightly with a pencil on the conductive side. These two glasses are drizzled with a potassium iodide solution (electrolyte) and fixed with the help of scotch tape. The Grätzel cell delivers a voltage of up to 333 mV. To increase the conductivity, a strip of silver paint can be applied to the edge of the cell [5].
Learning objectives: Grätzel cell, power generation, semiconductor

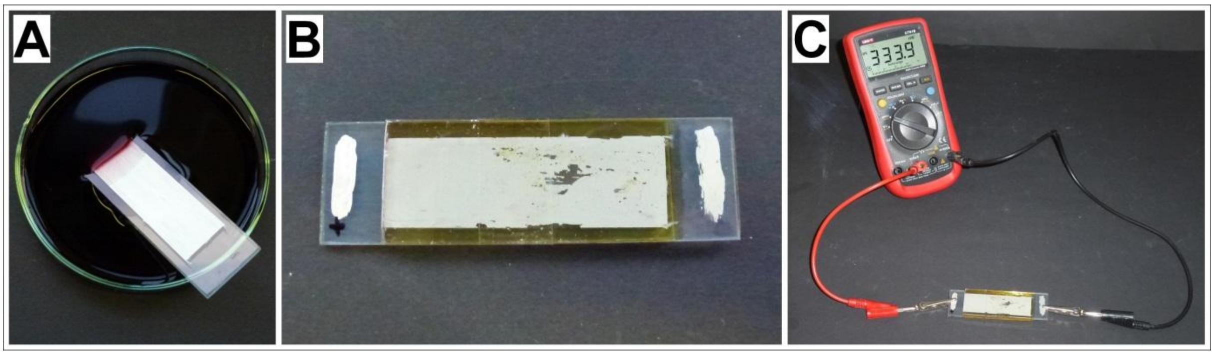

Fig. 5: A FTO-glass with TiO_2-vingar paste in elderberry juice (A) and the finished Grätzel cell (B + C)

4. Outlook

In this contribution, an approach to implement public outreach in high schools as part of a Collaborative Research Centre has been presented. The proposed project is currently being developed and practically implemented in partner schools of the Georg-August-University Göttingen. To improve the project, student evaluations, feedback and suggestions are being collected and

considered. Additionally, a teaching material box with the required chemicals and teaching materials is being compiled to be at the schools' disposal anytime. Apart from that, it is planned to provide the teaching materials online in order to assist teachers. The topics 'sustainable energy' and 'nanotechnology' are hardly found in German lessons so far. In order to establish and promote these important and scientifically current topics in schools, teacher training courses and presentations in schools will be offered as well.
Finally, it is important to mention that the scientific research and the methodology of the CRC undergo continuous developments. Therefore, the project described here and similar projects can be optimized frequently.

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