

Digital Learning Tools for Teaching “Alternative Solar Cells with Titanium Dioxide” (ALSO-TiO₂) - A Contribution to Sustainable Development Education

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Abstract The movement “Fridays for Future” is a good indicator for students not only having a very strong interest in sustainability, but also a high motivation to actively discuss this topic. For this reason, it is important for schools to provide the necessary basic knowledge and to give students insight into current research and application within the realm of sustainability education and SDGs. In this article digital learning tools for the concept “Alternative Solar Cells with Titanium Dioxide” (ALSO-TiO₂) are presented, that can be used to implement the topic “Solar Cells” in regular chemistry classes. The concept bridges the gap between the galvanic cell as a compulsory subject and dye-sensitized solar cells (DSSC), also known as Grätzel-cells. Thus didactic experiments, so-called photogalvanic cells, are explored with the help of an e-book. In addition, a small eye-tracking study is presented which was carried out in order to develop a new edition of an interactive animation.

Keywords: titanium dioxide, photogalvanic cells, solar cells, sustainable development education, e-book, animation, eye-tracking method, ICT, experimental kit, photochemistry

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1. Introduction

To keep on track with digitalisation of our everyday life Science Education has to prepare the future generation of teachers and develop strategies to implement digital formats at schools. The YouTube Study commissioned by the German “Rat für kulturelle Bildung” (council of cultural education) in 2019 supports this statement. The results show that digitalisation leads to fundamental changes in teaching, learning and the acquisition of knowledge. So an increasing number of students use YouTube as a learning platform in addition to regular school classes. The study shows in particular the strong interplay of analogue and digital formats in students’ learning processes [1]. Currently digitalisation has not yet reached a great number of German schools [2]. To embed digitalisation in school curricula, the Conference of the Ministers of Education and Cultural Affairs (KMK) in 2017 published a digital strategy with goals for schools and universities. An essential content is the targeted promotion of specific media skills, such as the use of digital tools and media for collaboration or for learning, working and problem-solving [3]. The next step is the so-called “DigitalPakt Schule” a measure of the German government to provide public incentives, to

equip schools with ICT and also to bring specialist’s knowledge to schools. The federal and state governments are providing a total of at least 5.55 billion euros for this purpose [4]. These are important steps to spread digitalisation among schools, which must be supported by research.

If appropriately orchestrated, digital media such as e-books and animations offer many advantages for chemistry lessons [5] and can be used to implement innovative topics in school curricula. These formats offer a new multimedia perspective on learning and, in addition to regular formats, provide a modern approach to self-directed learning.

One of the most pressing questions in research and technology is finding a solution for the future global energy supply. It is predicted that photovoltaics will play an important role in this field [6], so for decades solar cells have been the focus of interdisciplinary scientific research activities already. Therefore, photovoltaics should also be widely implemented in school curricula, not only in physics, but also in chemistry classes, with reference to Education for Sustainable Development (ESD).

Our workgroup belongs to the representatives of curricular innovation research, that aims at making innovative and future-oriented topics from everyday life and research accessible for the teaching of chemistry at school. Following our guideline “from established to innovative

topics" the new contents are embedded in didactic concepts with a connection to compulsory topics from school curricula. For the didactic concept "Alternative Solar Cells with Titanium Dioxide" (ALSO-TiO₂) didactic experiments and experimental sequences suitable for school use were developed. As an integral part of our curricular innovation research different kinds of media are designed to help implement the didactic concepts in chemistry lessons [7,8].

In this article we present two digital media formats of the concept "Alternative Solar Cells with Titanium Dioxide": an e-book and an animation. The e-book is a suitable addition to analogue media. It can be used without media discontinuity to carry out experiments, to document experimental results and for individual differentiation within a learning group.

Additionally, an animation was programmed which supports the learning process by visualising the chemical processes inside so-called photogalvanic cells. The aim was to enable teachers to use a wide range of analogue and digital media so that they could adapt them individually to the needs of their learning group.

2. The Concept "Alternative Solar Cells with Titanium Dioxide" (ALSO-TiO₂)

The concept "Alternative Solar Cells with Titanium Dioxide" (ALSO-TiO₂) offers a multi-step experimental approach towards the topic alternative solar cells for regular chemistry classes at secondary level. It consists of a sequence of four experiments that act as a didactic bridge from galvanic cells to Grätzel-cells and silicon-based solar cells (Figure 1). The procedures of the experiments can be found in literatures [7] and [8].

The starting point for this concept is the galvanic cell, which is dealt with as a compulsory topic of electrochemistry in regular chemistry classes in many countries. The general set-up of a photogalvanic 2-pot cell in the next step is similar to galvanic cells such as the Daniell cell. In contrast, photogalvanic cells contain a photoelectrode based on the semiconductor titanium dioxide. Upon irradiation with UV light a photovoltage and current can be observed.

With further cell set-ups, the students move on to an almost dry compact cell, which can also be constructed as a transparent version. In the last step, the students sensitize the titanium dioxide photoelectrode with natural dyes such as anthocyanins from raspberry juice [8]. The advantage of this multistep concept is that students can construct light-driven cells on their own with materials that are suitable for the use in schools and that they are prepared to be introduced to research on alternative solar cells, e.g. dye-sensitized solar cells (DSSCs).

3. E-books in Chemistry Education

E-books represent an optimal access for the use of digital media in the learning process and for this reason they can be considered important research topics in Chemistry Education. The *eChem Book* and *Multitouch Learning Books* are two examples of e-books for chemistry classes. They are designed with the aim of replacing textbooks in the future and represent digitized learning environments for schools. The *eChem Book* was developed in a DFG-funded cooperation project between teaching and learning psychology (Leibniz-Institut für Wissensmedien, IWM, Tübingen), and the department of Chemistry Education (University of Hannover) and commercial representatives from the educational sector (Schroedel-Westermann publishing house, SMART Technologies). It is a digital and interactive textbook for chemistry lessons on the topics "Introduction to the particle model" and "Dalton's atomic model" [10].

The e-books developed by Huwer et al. (Chemistry Education, Pädagogische Hochschule Weingarten), so-called *Multitouch Learning Books*, are another example of digital textbooks with interactive components. Icons are used to navigate through the *Multitouch Learning Book* and inform users about the underlying content. As in the *eChem Book*, help cards are integrated to enable differentiation. *Multitouch Learning Books* were produced for the beginners' classroom on the topics "particle models", "substances, mixtures and chemical reactions" and for advanced classes on the topic "phosphorus recovery" [11].

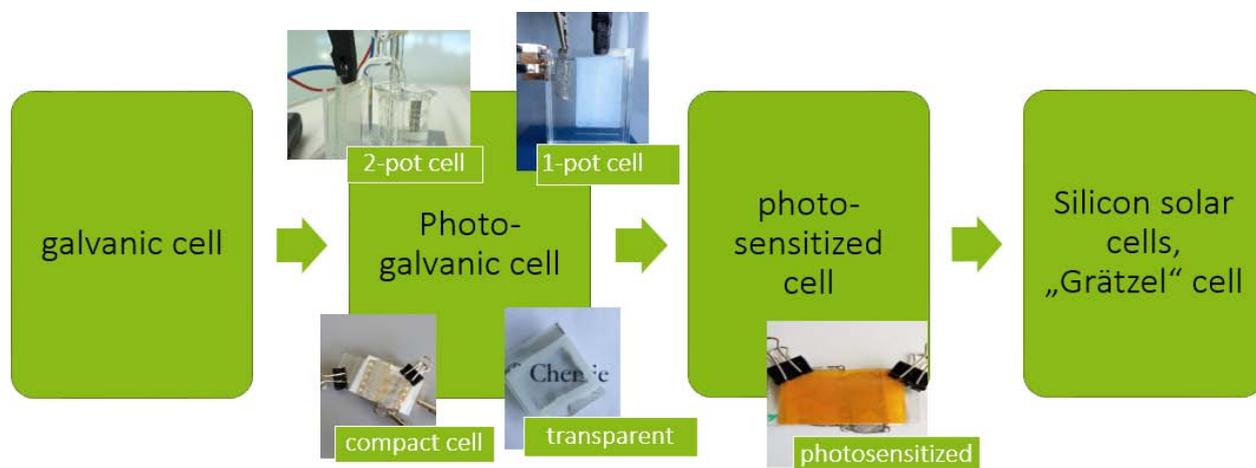


Figure 1. Steps of the concept "Alternative Solar Cells with Titanium Dioxide" (ALSO-TiO₂)

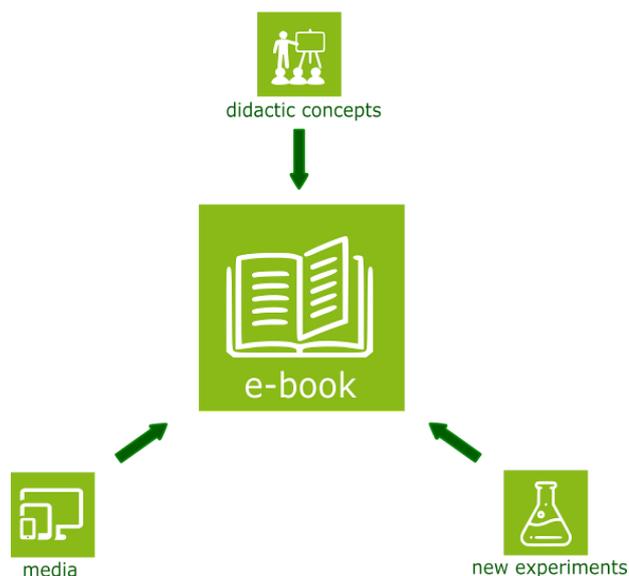


Figure 2. Components of the interactive e-book “Solar Cells with Titanium Dioxide”

The meta-study by Hillmayr et al. shows that digital media are part of modern science education [12]. However, the results show that especially a mixture between traditional and digital media is learning-effective. Taking this into account we designed our interactive e-book as a complementary medium to a classic textbook. The textbook continues to serve as a medium for the acquisition of basics and offers material for repetition and consolidation of core contents of chemistry. The e-book, which contains new experiments (Figure 1), didactic concepts and media, is then used to open up a new field of inquiry focussing on the innovative content. It can be explored experimentally as well as theoretically, using

different formats such as embedded texts, lab instructions, animations, videos, quizzes etc. (Figure 2). So the benefit of using this digital format is that one can address different channels of perception and has more space than in a classical textbook where information is delivered in a rather condensed way, e.g. in [13]. So the e-book offers a new way to implement innovative contents in chemistry classes via experiments and dynamic features of the digital medium.

4. Interactive e-book “Solar cells with titanium dioxide”

The interactive e-book „Solar Cells with Titanium dioxide” was created using the freeware *iBooks Author* and it was published in the *iBooks* format. This format offers an interactive surface by integrating widgets (Figure 3). Another non-interactive version of the e-book which can be opened in every operating system was also developed. The e-book is available in German and in a more compact version in English for native speakers or for bilingual chemistry classes.

The first chapter of the e-book starts off with a reference to galvanic cells. Users can reorganise and reflect on their respective prior knowledge. The set-up of the first experiment, the so-called photogalvanic 2-pot-cell, is analogous to a classical galvanic cell, so students can compare both cells. In order to understand the processes taking place inside the photoelectrode, which is the photoactive component of the 2-pot-cell, one has to explore the band model and the formation of electron-hole pairs in the semiconductor during irradiation with light.

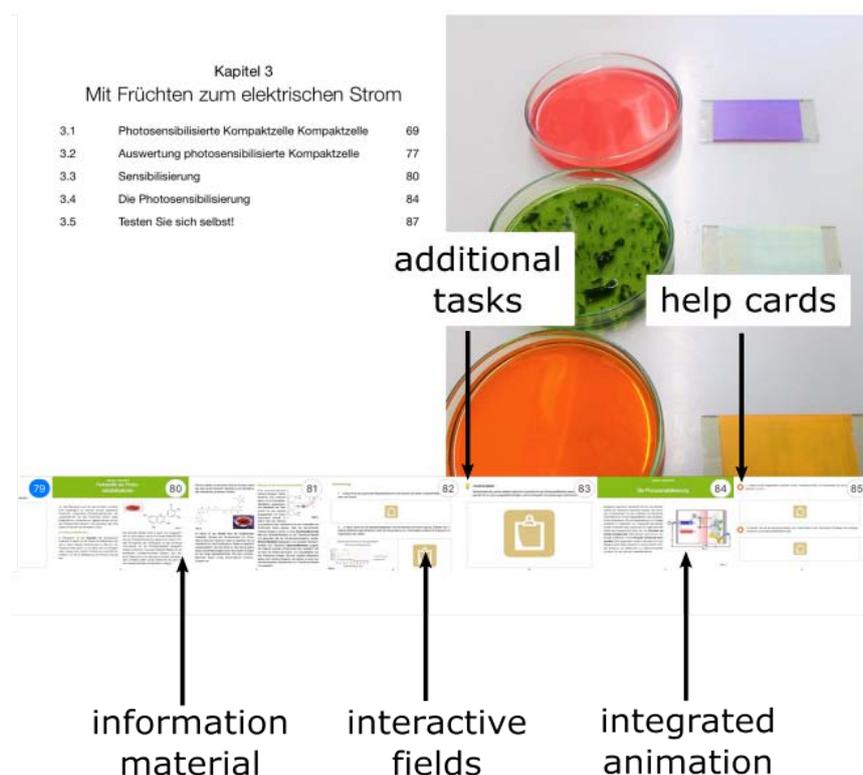
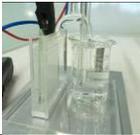


Figure 3. Typical features in the e-book “Solar Cells with Titanium Dioxide” (here: student version in German)

The following two chapters deal with further photogalvanic cells (1-pot and compact cell) and a photosensitized cell (Table 1). Each experiment is accompanied by evaluation tasks that also link the contents with each other. On the one hand, within the

modules there is a gradual increase in difficulty, which is particularly evident in the evaluation tasks. On the other hand, the experimental settings are designed increasingly open. So students finally move on towards planning their experiments in a self-regulated way.

Table 1. Content of the English interactive e-book “Solar Cells with Titanium Dioxide”

	Chapter	Experiments	Learning insights
1	From galvanic cells to photogalvanic 2-pot-cells	2-pot-cell 	Light energy is converted into chemical and electrical energy. Titanium dioxide is a semiconductor and absorbs ultraviolet light (UV).
2	Towards a sandwich-like set-up	1-pot-cell  Compact Cell 	The two important steps for energy conversion in a solar cell are: 1. formation of electron/hole-pairs and 2. separation of charge carriers.
3	With fruit juice towards electrical energy	photosensitized compact cell 	Organic dye molecules act as photosensitizers for titanium dioxide. The dye molecules absorb light from the visible spectrum (VIS). Electrons are promoted further to TiO_2 and into an external circuit. The dye-sensitized cell can be driven by sunlight.

Experiment 2: Evidence of reaction products

Procedure:

1. Observe if anything has changed in the two half cells.

2. Check the resulting product in the half cell with the photoelectrode as follows: **Extract** a few drops of the electrolyte solution and drop them onto a spot plate with drops of potassium iodide/starch

3. To compare, repeat the experiment with two **control samples**:

- Potassium iodide/starch solution + potassium bromide solution

Potassium iodide/starch solution + iodine crystals

Observations:



Disposal: Neutralise the hydrochloric acid. The photoelectrode and the counter electrode can be **rinsed** with distilled water and reused.

Figure 4. The pop-over window of a vocabulary help: a German translation pops up.

When designing the e-book, one focus was on a strong interaction of images and text elements in order to use the multimedia principle for a greater learning effectiveness in the sense of the cognitive theory of multimedia learning by Mayer [14]. For this purpose, all experimental set-ups are integrated as drawings and as photographs. In addition, using the widget *interactive image* students can explore the components of the set-ups in detail. Touching on components opens up pop-over text boxes. These text boxes have great potential, especially for an individual differentiation in classes. Weaker students as well as high achievers should benefit from learning materials [15]. This is taken into account by integrating help cards as well as additional tasks. The differentiations are marked by icons, a life buoy for help cards and a light bulb for additional tasks (Figure 3).

Touching an icon opens a pop-over window in which the help card is integrated. For a bilingual setting (English and German) vocabulary help has been designed in the same way (Figure 4). By touching a book icon placed next to a word, the respective German translation will open as a pop-over-window. Words that are underlined in red are also linked with a vocabulary sheet containing the most important words. So students can decide for themselves whether they want to use the contents of a help card or not.

To support self-directed learning we included multiple-choice or assignment tests (Figure 5). A learning assessment at the beginning of each unit is intended to make students activate their prior knowledge. Such tests

were also integrated after each experiment and can be used to check the new learning status. Thus students are provided with tools for self-diagnosis and they can work independently on possible gaps in knowledge [16]. The tools also help to revise the contents learnt.

Additionally, assignment tests at the end of a unit help to promote the use of proper scientific language as they focus on the most important terms of the module and help to assign technical terms to correct contents. At the same time, comparing these tests with the introductory tests gives students an insight into their learning outcomes.

Ultimately, interactive fields were integrated into the interface so students can use the e-book as digital laboratory companion. Using HTML5 widgets from *Bookry*® one can integrate interactive text and character fields (Figure 3). *Bookry*® widgets can be used when the mobile device is online. The content entered by the user is then stored in the cloud.

We also developed a full teacher version of the e-book containing solutions to the tasks (Figure 6). In addition, didactic hints are given on how to arrange the lessons and on how to link the experiments. Also experimental hints are included for a successful construction of the cells. The teacher version also contains further videos, which show the assembly of the different cells step by step. Teachers can use the videos for their own preparations and they can decide to which extent these will also be made available to the students for additional experimental support.

Photogalvanic Cells
Test yourself!

1. Processes in the photogalvanic cell

Find the right statement!

A. In the photogalvanic cell, the photoelectrode with titanium dioxide is the anode at which the reduction takes place.

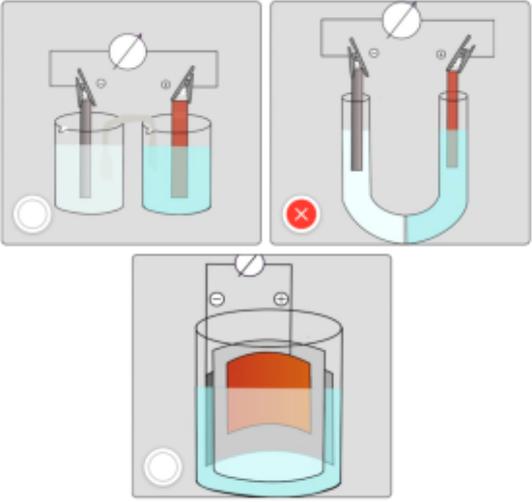
B. Exposure to UV light excites the titanium dioxide and electrons are transferred to EDTA ions.

C. The particles in the EDTA solution serve as electron donors and electron acceptors.

Antwort löschen

2. Geometry of cells

Which of the cell geometries is most efficient?



Erneut versuchen

Figure 5. Learning assessments as multiple-choice-tests

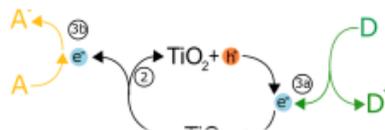


Additional tasks:



1. Propose a hypothesis based on your observations about the function of the titanium dioxide.
- 2.

they move to the counter electrode via the external circuit. There, the protons (H^+) in the electrolyte are reduced as electron acceptors to hydrogen.



3. The potassium iodide/starch solution is indirect evidence of the product of the half cell with the potassium bromide solution and the photoelectrode. Explain this evidence with the help of the **electrochemical series**.

The potassium iodide solution is used to test the bromine molecules. During the reaction, the bromide ions are oxidized to bromine molecules because their electrons can fill the holes in the titanium dioxide. This isn't visible to the eye, because the amounts produced are very small.

The solution with the resulting iodine molecules is a Lugol's solution. The existence of

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Figure 6. Integrated answers to additional tasks in the full teacher version

5. Eye-tracking Study as Basis for a Redesign of an Animation on Photogalvanic Cells

From the perspective of learning psychology, moving images such as animations or videos represent a higher connection to reality than static graphics. A meta-analysis by Höffler and Leutner indicates that there is an average superiority of animations over static representations with regard to learning success [17]. Animations have been developed in the department of Chemistry Education at the University of Wuppertal for many years already. Thus various animations have been produced for different learning and teaching settings as well as for the exploration of various classical and innovative topics of chemistry, e.g. animations on the topics “Photo-steady-state”, “Acids and Alkalis” or “Organic Photovoltaics”. They can be accessed and downloaded for free from our website [18]. Many of them were translated into English and other languages such as French, Spanish or Russian. There is a Flash-animation on photogalvanic cells by Bohrmann-Linde, that has been frequently used in university courses as well as in the so-called “*Chemie-Labothek*”, an extracurricular chemistry learning space in the department of chemical education at the University of Wuppertal [19]. With this interactive animation, the processes taking place in the photogalvanic cells can be independently explored by students. Based on the original animation, an optimized new HTML5-based animation, which should be integrated into the didactic concept ALSO-TiO₂, was realised.

In two research projects from 2011 to 2014, Lowe and Ploetzner investigated which design principles prove to support or hinder learning with animations in general [20]. The design principles developed by Lowe and Ploetzner have not yet been examined with regard to the representation of chemical processes. A questionnaire-based evaluation of “*Chemie-Labothek*” shows that the Flash-animation on photogalvanic cells is learning effective. What is yet to be investigated is how students intuitively work with the animation. To get an insight into this question, a small eye-tracking study was carried out.

Eye-tracking studies are already an important part in chemistry didactic research in the context of implementation and observation of experiments [21]. In addition, Graulich et al. investigated eye movements of students while handling mechanisms of organic reactions to gain an insight into solution strategies for higher education didactics [22].

In his examination thesis Sebastian Kläger investigated the students' use of the animation “Photogalvanic Element”. The study was carried out in cooperation with the IWM Tübingen. The eye-tracking study was accompanied by a test of prior knowledge and a post-test. The participants of the study were students from second to tenth semester who enrolled in a programme preparing them to become chemistry teachers ($n = 12$). In the study so-called “areas of interest” (AOIs) were defined on the programme surface. From the evaluation of use of the animation, the AOIs and the feedback forms of the post-test, Kläger deduced recommendations for a future modification of the animation [23]. These were the basis for the development of an optimized version of the animation.

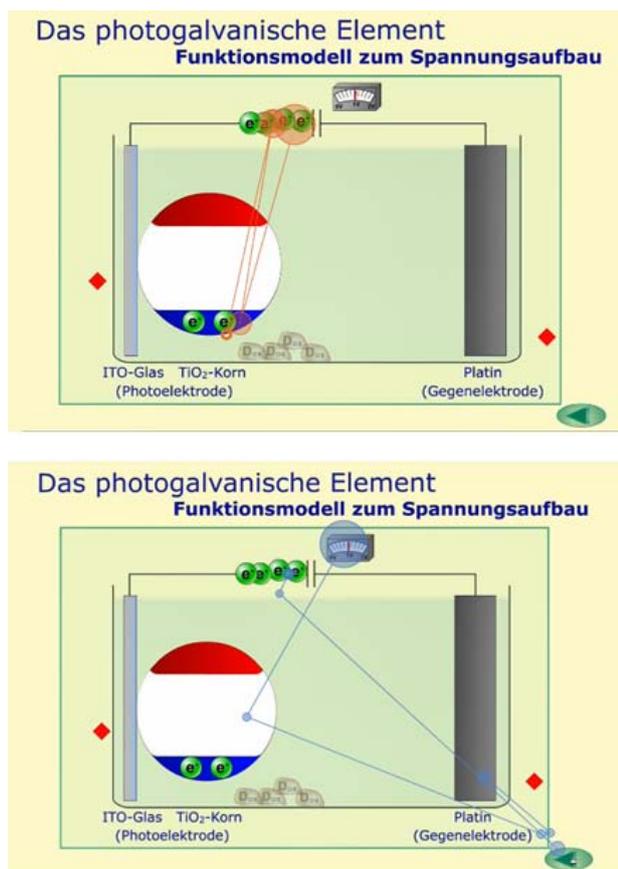


Figure 7. The eye movements of two users using the German version of the animation “The Photogalvanic Element”, screenshots of the same moment. The size of the circles can be related to the duration of the user’s gaze

One of the feedback answers was that a participant wished to have more opportunities of navigation within the sequence of the visualisation of the processes inside the cell on the particle level. He stated that the movement of particle was too fast, making it difficult to observe the simultaneous processes taking place in the cell. According to Petko, a pause button and a play button should be integrated in an animation, enabling the user to adapt the sequence of the animation to his or her individual needs and own pace [24].

Current research results by Wagner and Schnotz also show that a flexible combination of dynamic and static images accommodates individual learning requirements of the viewer, so that learning goals can therefore be better achieved by a heterogeneous learning group [25]. Therefore, in the new animation three buttons, a play- and a pause-button as well as a back-button, starting the animation from the beginning, were integrated, so the observation can be individually adapted by the user.

Furthermore, the students considered the energy-band model to be a generally difficult concept and had problems to transfer the processes to the particle level. For this reason, two different animations were developed in which the processes are visualized using two different models. Also the students pointed out that in the original animation, the acceptor particles are not displayed during the voltage measurement, but only during the measurement of electric current, which they found confusing. Thus in the new animation there is a continuous representation of the particles during both measurements.

Additionally, conclusions can be drawn from the recording of the eye movements (Figure 7) and from an analysis of the AOIs. One question in advance was if the depicted multimeter is perceived by the users in the functional model for voltage measurement. As Figure 7 shows, the multimeter is actually gazed at by some of the users. But on average the electron pressure, represented by the accumulation of electrons, was more in the users’ foci. For this reason, in the new animation the multimeter was more prominently integrated as a component of the external circuit, so that it is perceived as an integrated component of the experiment, linking from the particle level to the continuous level.

In addition, the number of displayed donor and acceptor particles was reduced from four to three each. A result of the eye-tracking intervention was that a threefold repetition of the processes was sufficient to be understood by the user. For this reason, the number of particles was reduced by one in order to prevent cognitive overload or boredom.

6. Revised Version of the Animation “The Photogalvanic Cell”

For the development of the revised version of the animation “The Photogalvanic Cell” the software *Animate CC* by Adobe was used. With this software one can create a HTML-canvas, which combines HTML5 and Javascript for an interactive animation. The advantage compared to coding with Flash is that HTML5 can be opened in every operating system and can also be retrieved from mobile devices. A full-screen format (800 x 450) was chosen, which however adapts its size to the screen of the retrieving medium. The animation can be used by itself, but in the e-book a worksheet is provided that guides the user through the medium.

Contents of this animation in general are photogalvanic cells in the set-up of 2-pot- and the 1-pot-cells and the chemical processes transforming light energy to electric energy (Figure 8).

The complete animation contains three chapters that can be individually addressed by a roll-up-menu (Table 2). In the first chapter “1. Set-up” users can explore the components of the two cells. The first screen consists of two schematic representations of the respective set-ups and a grey box with information in between (Figure 9). Via a mouse-over movement across the components, information on the various materials and chemicals is provided. By contrasting the 2-pot-cell with the 1-pot-cell, students can compare the two set-ups with each other in the same frame.

In the second chapter “2. chemical processes”, the user selects one of two different visualisations of the chemical processes. They differ in their representation using either the energy-band model or the particle model. The representation using the particle model shows the so-called hopping process, that is the bidirectional drifting of electrons and holes by a “hopping” mechanism. To understand the processes in this animation, electron-hole pairs as charge carriers in the semiconductor are assumed to be prior knowledge, which could be gained e.g. by working with the above mentioned e-book. Using the

representation with the energy-band model (Figure 10) students can understand the connection between the suitable light energy (UV-light) and the induced chemical processes. In both versions, a 1-pot-cell arrangement was chosen in order to make the animated particle movements as clear as possible. The corresponding worksheet in the e-

book provides information on the energy-band model. After having chosen a model, the user automatically opens information on the different icons and characters picturing components (e.g. particles) of the animation. One should explore them before moving onwards to the measurement of voltage or current.

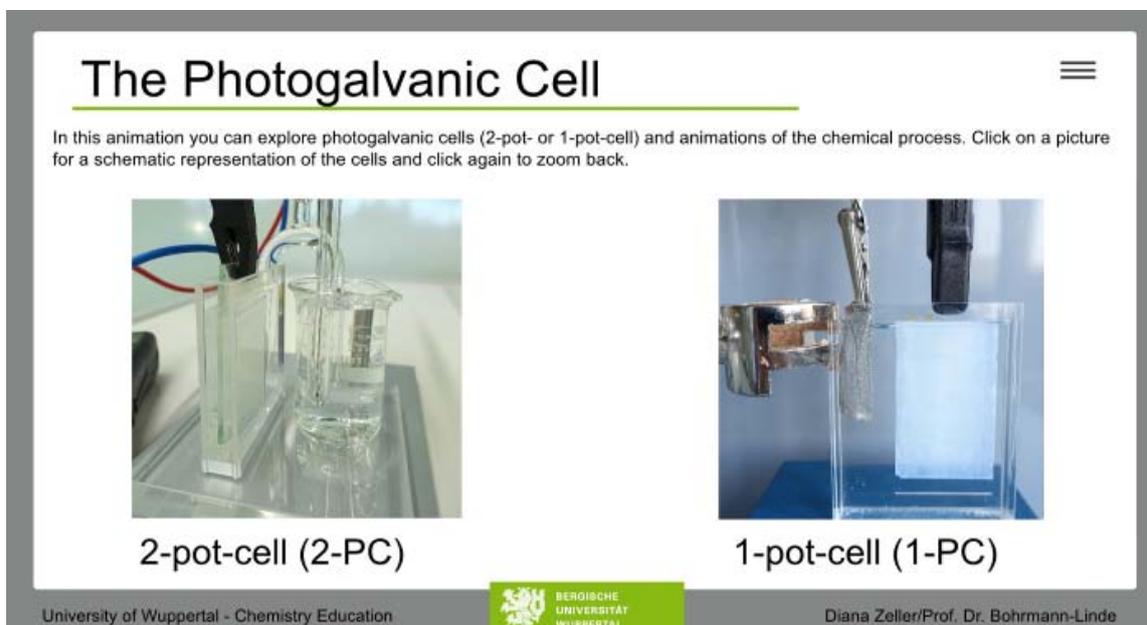


Figure 8. The first screen of the animation “The Photogalvanic Cell”

Table 2. Content of the Animation “Photogalvanic Cell”

Chapter	Content
1 Set-Up	<ul style="list-style-type: none"> • 2-pot-cell • 1-pot-cell
2 Chemical Processes	<ul style="list-style-type: none"> • Energy-band model/hopping processes • voltage and current measurements
3 Information	<ul style="list-style-type: none"> • E-book • Teaching material • Titanium dioxide

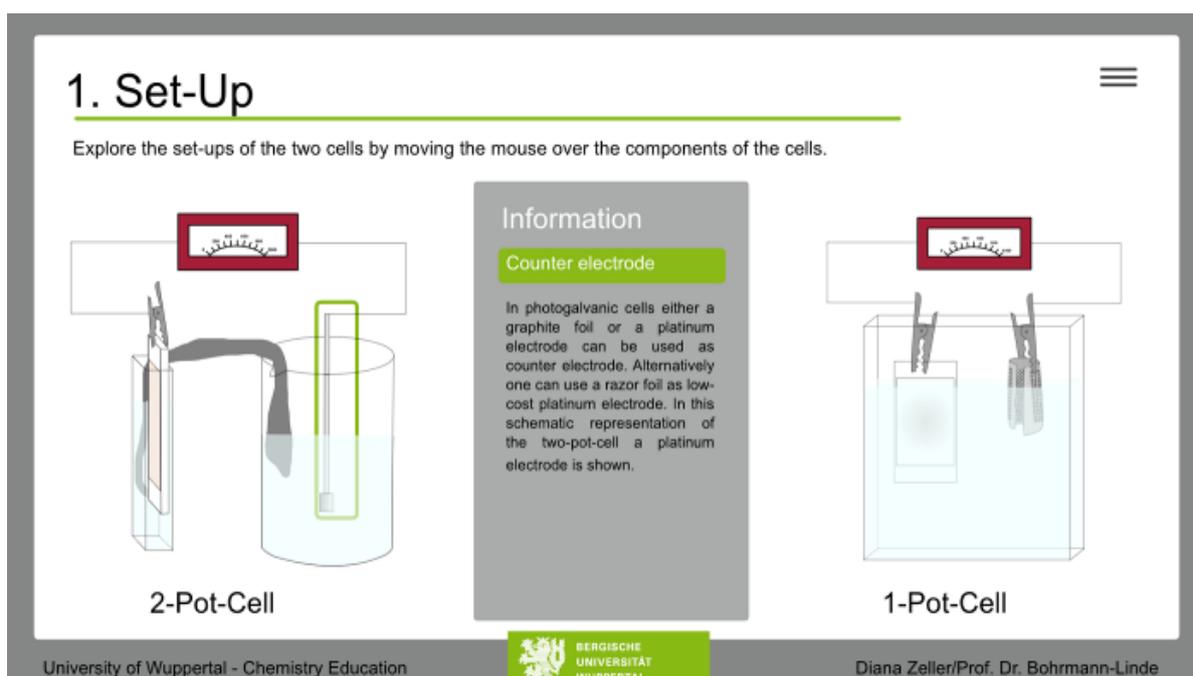


Figure 9. First screen of chapter “1. Set-Up”

The chemical processes during voltage and current measurements on the particle level are explained in a differentiated way in the animation. For the animation of the chemical processes, the UV-light irradiation is represented by a wavy arrow which hits a valence electron in the valence band of the semiconductor. The excited electron is transferred to the conduction band, while a hole remains in the valence band. The hole is then “stuffed” by an electron from a donor particle while this particle is irreversibly oxidized and sinks to the bottom (Figure 11). The electron in the conduction band finally moves in the outer circuit, so that an increase of measured voltage at the multimeter is noticeable. The electron

pressure, which is built up during voltage measurement due to the high internal resistance of the multimeter, is represented in the animation by the accumulation of electrons.

In the animation on the processes during the measurement of current, visualised using the particle model (Figure 12), the excited electrons drive a motor as they move through the outer circuit (though it should be made clear that it takes more than four electrons to drive a motor) and reduce an acceptor particle at the counter electrode. After the redox reactions, the titanium dioxide is completely regenerated and the chemical processes can start all over again.

2.1 Chemical Processes: Energy-Band Model!

Explore the schematic representation. Then choose a measurement.

Information further elements:

h^+

e^-

Measurement of:

Voltage

Current

glass | titanium dioxide layer | electrolyte | Pt-electrode

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Figure 10. First screen in chapter “2.1 Chemical Processes: energy-band model”

2.1.1 Voltage Measurement

mV

LB e^-

VB e^- h^+ e^-_{ox}

D A

A A

back

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Figure 11. Voltage measurement visualized using the energy-band model

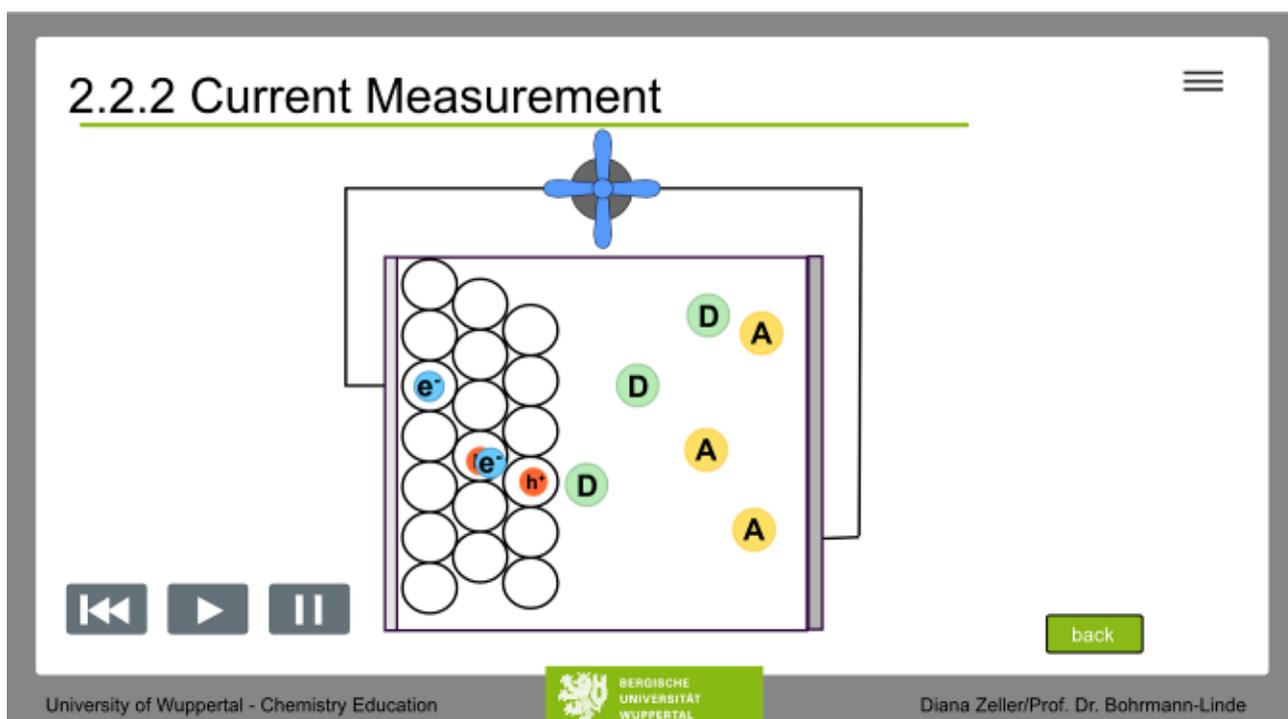


Figure 12. Current measurement visualized on the particle level

In the third chapter "3. information" one can find another sub-unit with more information about the didactic concept ALSO-TiO₂. This information is helpful for those users who address the animation independently from the e-book. For teachers, who are interested in learning more about the presented contents, there is also a contact address for further information.

7. Implementation in Schools

As mentioned before the multimedia tools were developed for the teaching unit ALSO-TiO₂ that can be explored starting from the contents of electrochemistry in high school classes. Whereas the subject of absorption of UV light can be related to the field of energetics, the photosensitizers also fit into the mostly optional topic colour and dyes. Even though the unit is developed aiming at regular chemistry classes, it offers numerous cross-curricular connections that are excellently suitable for projects, working groups or interdisciplinary courses.

The didactic concept ALSO-TiO₂ is part of an experimental kit "Chemical Experiments and Media on Titanium dioxide", *ChEM-TiO₂*, that was created within the doctoral thesis of Zeller. *ChEM-TiO₂* contains experiments, materials and two concepts that intend to enable students to explore the substance titanium dioxide and its properties [26]. The focus is on the conversion of light energy into electric energy, thus photogalvanic cells based on TiO₂ play a main role in this kit. The contents as well as the experiments and materials anchor on the students' prior knowledge of electrochemistry and motivate them to explore titanium dioxide as a substance in their everyday lives. In addition, the presented multimedia tools support cognitive access and facilitate the transfer from regular contents in chemistry classes to current research and application areas.

8. Conclusions

"Fridays for Future" as a global movement shows that sustainability is a current and important topic for today's generation of students. So chemistry classes must increasingly focus on sustainability as a primary aim to provide a well-founded scientific background for participation in current discussions and public debates. The wide use of titanium dioxide in research and application opens a highly up-to-date context, which offers an innovative content for sustainable development education in regular chemistry classes. Dealing with alternative solar cells with titanium dioxide serves as a basis to motivate students to deal with the conversion of solar light to electric energy, to critically reflect on political discourses and to make decisions for a sustainable future in everyday life.

For the implementation of the ALSO-TiO₂ concept, two multimedia tools were designed, which contribute to sustainable development education with focus on the context of solar cells. Additionally to the analogue materials provided in the experimental kit (Figure 13), the interactive e-book offers a different learning access for students through its interactive interface. The teacher can thus choose from a range of media and from differentiating elements regarding the needs of his or her learning group.

For the redesign of an existing Flash-animation an eye-tracking study was carried out to identify aspects of optimizations based on the users' behaviour. The animation was redesigned regarding the results of the study, and is now programmed on a HTML5 basis. The integration of the target group with regard to a participative approach proved to be beneficial. Further studies are currently planned in order to gain information on a changed usage behaviour due to the redesign of the animation or on a possibly improved comprehensibility of the chemical processes in the cell.



Figure 13. Experimental kit *ChEM-TiO₂* for the exploration of titanium dioxide in its various functions

Approaching the topic alternative solar cells via the digital world that the students feel at home in, helps to get them motivated to independently explore and discuss current research topics on sustainability. In the best case, it will also be possible to address the next generation of scientists who, with their career aspirations, want to find answers to the pressing question of future energy supply themselves.

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