Science in the Spotlight: Didactic Reconstruction of Current Research for Chemistry Education

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Abstract

Fundamental scientific research and its results are very difficult to understand for the general public since they are mainly communicated between experts in the respective field and presented in a way that laypersons cannot easily understand. This leads to a separation between science and society and consequently to a lack of awareness and often a lack of mutual appreciation. The didactic reconstruction of current research results addresses this challenge by making future-oriented topics and their associated research methods accessible to society.
The field of photochemistry is currently subject of intense research and offers excellent learning opportunities. Related technologies find broad applications in everyday life, science and technology, ranging from solar collectors and photocatalytic wastewater treatment to light-emitting diodes (LEDs) and beyond. Due to their strong connection to everyday life, their great significance in the present and the future, their possibilities for interdisciplinary approaches and contexts, these topics offer just as great a potential for teaching in formal as in non-formal educational programs. From a didactic point of view, they offer a variety of interdisciplinary learning opportunities and numerous references to the basic concepts of energy (conversion and storage), chemical reaction and structural properties. In addition, there are numerous links to many classical contents and content fields of chemistry lessons at secondary level II.
In our article we present how current research results on photocatalysis can be reconstructed didactically and implemented into schools and student laboratories. In close collaboration with chemistry research groups, teaching concepts, teaching materials and (model) experiments have been developed that can be carried out with harmless chemicals and low cost analytics.

Keywords: Chemistry Education, Didactic Reconstruction, Photocatalysis

1. Introduction

Good communication between science and society is of vital relevance and interest to both groups. This becomes particularly clear in the current exceptional situation when, for example, research processes for the development of drugs and vaccines to treat COVID-19 have to be communicated to the public in an understandable way. Strong relations to science are also of great importance for school chemistry education and vice versa: the subject of chemistry is often perceived by students as "abstract" and "lifeless" [1] and over 70% of students cannot imagine taking up a STEM profession [2].
The examination of current research results within exciting contexts and with a high level of relevance to everyday life offers a variety of opportunities to contribute to the solution of both problems. Future-oriented topics and their associated research methods can be made accessible to society through the didactic reconstruction of current research. This offers students as well as teachers not only motivating learning opportunities and contexts, but also enables participation in social discourses in the sense of a *Scientific Literacy* and reveals new career perspectives. It offers the interested public the opportunity to encounter future technologies to obtain comprehensible first-hand information and to participate in scientific and educational policy debates.

2. Photochemistry: Chemistry in the right light

Reactions driven by (solar-) light are the main focus of the German transregional collaborative research center 234 CATALIGHT (TRR 234), hosted by Ulm University and Friedrich-Schiller-University Jena with additional project partners at Max Planck Institute for Polymer Research Mainz, Vienna University and the Institute for Photonic Technology Jena. To pave way for a broad usage of abundant

solar energy, CATALIGHT develops molecular light-driven chromophores and catalysts, and establishes concepts for their integration into soft matter matrices.
The thematic orientation of CATALIGHT offers excellent opportunities for school chemistry education. Chemical reactions with (solar) light represent the basis of numerous processes that enable life in the biosphere. They also have broad applications in everyday life, science and technology, ranging from solar collectors over photocatalytic wastewater treatment to light-emitting diodes (LEDs) and beyond. Due to their strong connection to everyday life, their great importance in the present and future, and the possibilities for interdisciplinary considerations, they offer as much potential for teaching in formal as in non-formal educational programs. From a didactic point of view, they further provide a variety of interdisciplinary learning opportunities and numerous references to the basic concepts of *Energy*, *Chemical Reaction* and *Structure-Property-Relations*. In addition, there are numerous links to many classic contents and content areas of chemistry lessons at secondary level II [3,4].
For these and other reasons, the topic of "chemistry with light" is the subject of research by several didactic research groups; however, the core curricula and syllabi are still mostly limited to superficial considerations and a few examples of application, such as photosynthesis or solar collectors. Current research on these objectives has rarely been taught in schools and student laboratories to any great extent, nor has the impact been considered, that such new technologies can contribute to society as a whole (*e.g.* energy supply, mobility, climate change).

3. CATALIGHT: Shedding light on chemistry

Within CATALIGHT, new photosensitizers, photocatalysts and suited soft matter matrices for the immobilization of these chemically active components are developed. To understand the interaction between all components of the reactive systems, an interdisciplinary effort is required to generate a fundamental understanding rather than gaining specific insights into only a particular chemical system. Consequently, research activities cover the fields of theoretical, physical, organic, inorganic and analytical chemistry as well as physics and chemical engineering. Below, two selected research areas are briefly presented.
One research area within CATALIGHT performs photochemistry in a soft matter membrane-material that is very similar to the natural material of cell membranes: phospholipid bilayers. In water, such membranes form so called vesicles, which serve as nanoscopic chemical reactors. In this project, the membrane itself is used to self-assemble chromophores to absorb several colors of the visible light and funnel the light energy from the membrane surface to the inner water interface of the nano reactor where the energy is used to convert substrate into product (see Figure 1 and 2).
With regard to chemistry education, direct links exist to the subject area of surfactants, which are typically taught in secondary level II. Since amphiphilic molecular structures and micelle formation are well known by students, these “classic contents” can easily be transferred to a current research context within CATALIGHT.

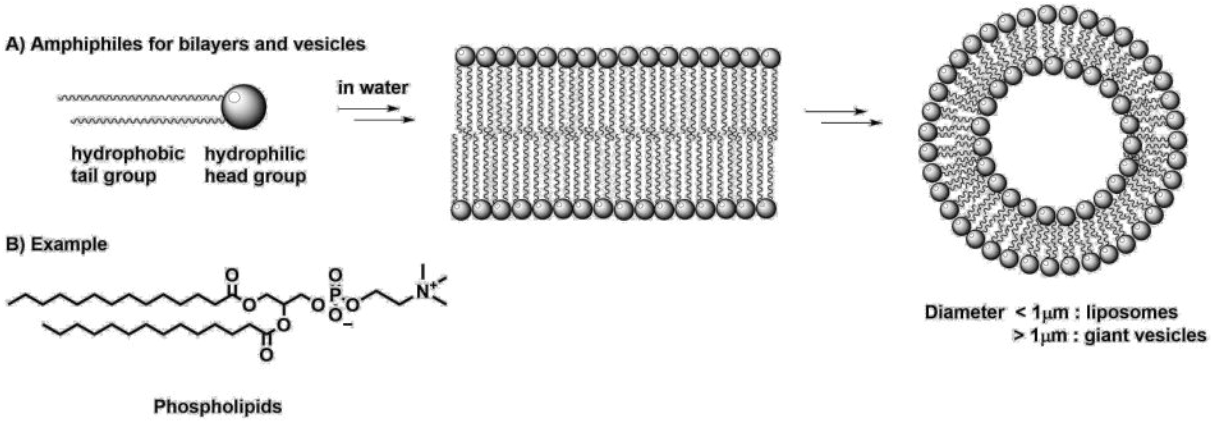

Figure 1: A) Self-assembly of amphiphilic molecules in water into bilayers and vesicles. **B)** Example of bilayer forming amphiphiles: phospholipids.
Building on experience of energy transfer within such membranes [5], this process is fine tuned to enable long range energy transfer within the membrane. The specific energy transfer mechanism is called “FRET” (Förster resonance energy transfer) and is very often used in biological and biochemical context to “measure” distances on the nanometer to sub nanometer scale in biological material such as proteins using luminescence and luminescence quenching via FRET (Nobelprize 2008) [6]. Specific

chromophores are chosen based on their luminescence properties, excited state reactivity with respect to photocatalysis and their ability to co-assemble with the phospholipid bilayer.
An example of a luminescent chromophore is shown in Figure 2: A luminescent metal complex with hydrophobic alkyl tails is perfectly suited to integrate into phospholipid membrane vesicles. In combination with other chromophores, absorbing different colors of the visible spectrum, light harvesting via energy transfer is enabled, which can be monitored and used for luminescence spectroscopy and photochemical reactivity (see Figure 2).

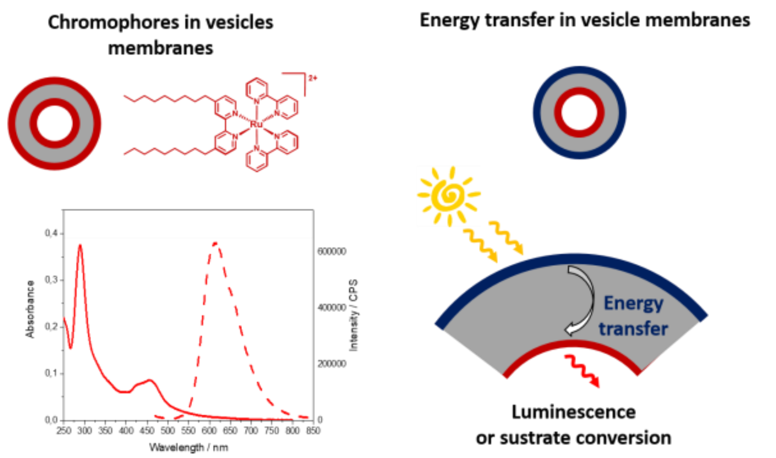

Figure 2: Left: Chromophore in vesicle membrane including absorption and luminescence spectrum. **Right:** Scheme of targeted vesicles with chromophores absorbing different colors of light and funneling the energy to the inner vesicle compartment for photochemical oxidation of substrate to product.

Photochemical reactions heavily depend on the reaction conditions. As for thermal reactions, parameters such as temperature, concentration, pH-value, etc. influence reaction rates and selectivites. Beside this, intensity and wavelength of the light reaching the chemically active species are not only further parameters that govern the performance of the reaction but the most important [7]. During experimental work, this influence often results in poor reproducibility of experiments since conventional experimental setups are prone to slight changes of the overall arrangement. Hence, the irradiation conditions and consequently the most important reaction parameter, the light intensity, randomly changes. To minimize this experimental error, rapid prototyping and additive manufacturing are applied within CATALIGHT to develop and distribute experimental setups that prevent changes of the irradiation conditions (see Figure 3).

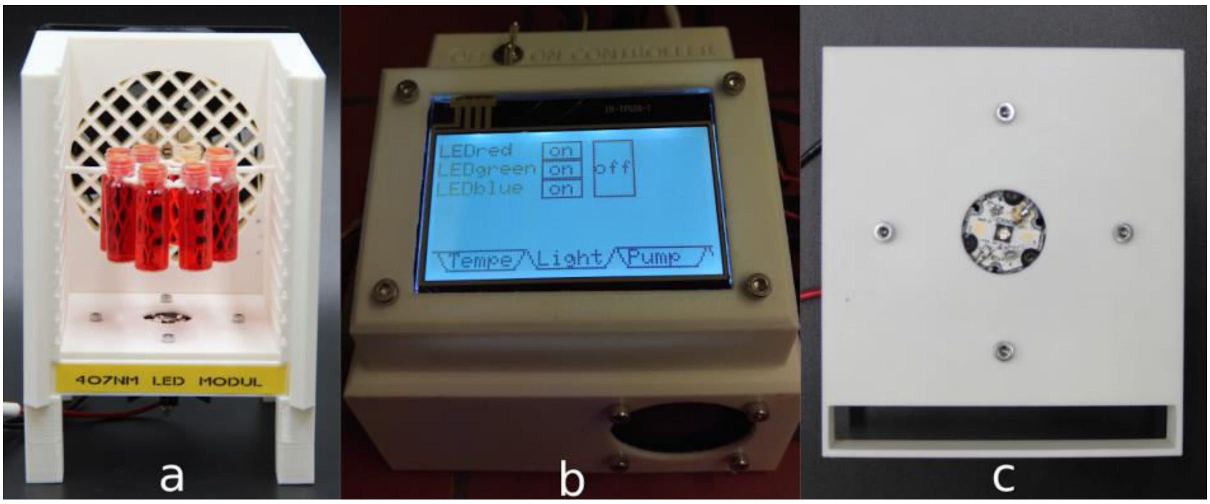

Figure 3: **A)** Experimental setup for screening of photocatalytic systems, **B)** control unit for light sources and other devices, **C)** modular LED cartridge, available with different light sources.
The flexibility that is gained by additive manufacturing allows for an easy adaptation to particular experimental requirements of the various photocatalytic systems that are investigated within the TRR234. Furthermore, manufacturing costs are low and processing times for individual adaptations short. This allows for the necessary wide distribution across the different projects and swift response to practical experiences and new scientific insides.

This concept is well suited for transfer to school education since it covers aspects of physics, physical chemistry, photocatalysis as well as analytics, statistics and planning of experiments. It further introduces engineering aspects like design of reactors and experimental setups on the basis of modern and also popular and easily available 3D-printing techniques.

4. Reconstruction for School Chemistry Education

For a successful transfer of these contents from CATALIGHT to schools and the public, there are three central challenges in particular:

1. **Didactic reconstruction:** Due to its high specialization, current (fundamental) research is usually very demanding and difficult for learners to comprehend. Especially for the understanding of light, there are inaccurate preconceptions or misconceptions on the part of the learners [3], which have to be addressed.
2. **Experiments and analytics:** Standard equipment and chemicals in research cannot be used in schools due to their high costs and/or hazard potential. In addition, schools and student laboratories typically do not have access to analytical methods.
3. **Instructional approaches and in-service training:** Many teachers are motivated to teach new subject areas in their classes, but often perceive multiple barriers to teaching new subject areas in their classes. These include, in particular, lack of subject knowledge, lack of teaching materials, and lack of teaching time.

This results in three fields of action in which the above-mentioned challenges are to be addressed, new impulses for chemistry teaching are to be developed and the dialogue with the public is to be promoted.

Field of action 1: didactic reconstruction

For the research process, the model of didactic transfer research [8] is used as a foundation, which opens a structuring framework for the scientific development of the contents. Figure 4 visualizes the three sections, which include (1) the didactic reconstruction of the contents in cooperation with scientists, (2) the development of teaching materials in a cyclical process of conception, testing, evaluation, and optimisation and (3) the final dissemination of the tested materials into science and teaching practice. An example of a practical implementation of the model can be found at [9].

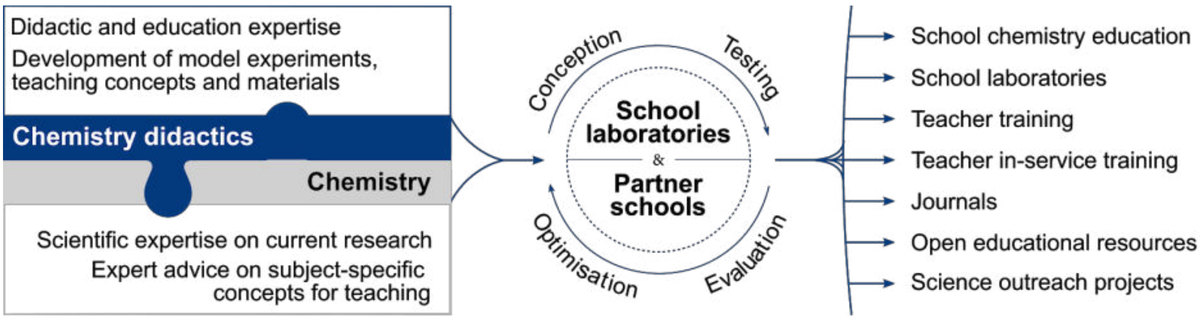

Figure 4: Model of didactic transfer research [8].

Field of action 2: digital low cost analytics

One challenge for the development of meaningful model experiments is the lack of possibilities for measurement data acquisition in the classroom. However, this represents a central aspect of scientific-experimental investigations, which is rarely reflected in teaching for a multitude of reasons. Schools often lack the funds to purchase and maintain the measuring instruments. In addition, many existing devices are not designed for use in the classroom.

This challenge is met by using the digital low-cost measuring station LABPI with the aim of opening up new experimental possibilities for STEM teaching [10]. Instead of individual solutions for each unit, LABPI represents an open platform on which up to five measuring variables can be recorded simultaneously. This is achieved by combining single-board computers (Raspberry Pi) with powerful (miniature) sensors, which are widely available and sometimes cost only single-digit euros. With an adapter board and the corresponding software, measurements of pH, temperature, conductivity as well as photometric investigations are currently possible, providing basic analytics for chemistry teaching.

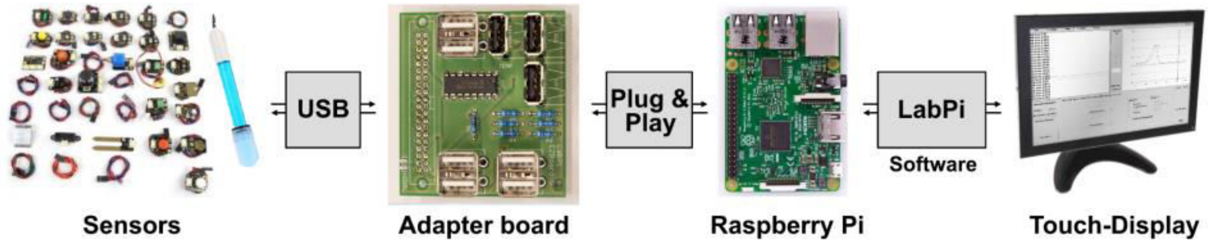

Figure 5: Components and schematic representation of the LABPI build.

Field of action 3: dissemination and outreach

The developed and tested teaching materials (see Figure 4) will be made accessible to students, particularly via regular teaching in upper secondary schools; by integrating them into formal education, learners can benefit from the offerings both regionally and nationally. In addition, we will also develop materials and courses for student laboratories, so that interested learners can get to know this offer on their own initiative.

To enable or facilitate the teaching of the subject area to motivated teachers (as multipliers), we provide the developed materials (experiments, worksheets and sample solutions) as Open Educational Resources. At the same time, a teaching sequence is created on this basis, which can be used in regular lessons with the associated handouts. Thus, teachers are relieved in the preparation of lessons, but retain the flexibility to adapt the unit depending on the learning group, time and interests.

5. Conclusion and outlook

The subject area of photochemistry offers excellent learning opportunities for consideration in chemistry classes. In addition to numerous everyday connections, challenges facing society as a whole can also be discussed and evaluated in a context-oriented manner. The research work in the transregional collaborative research center CATALIGHT offers an ideal environment for this and will be didactically reconstructed for schools and student laboratories in the coming years.

6. Acknowledgements

This research was funded by the Deutsche Forschungsgemeinschaft DFG as part of the transregio collaborative research center TRR234 "CATALIGHT" (364549901), projects B8, C6 and Ö1.

7. References

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