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From Surfactants to Membranes – A Science Outreach Project Connecting School and University

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Abstract
Biological membranes play an essential role in biological systems and are, among others, involved in cell division, synthesis of macromolecules, transport processes and energy metabolism. The Collaborative Research Centre (SFB 803) at the Georg-August-University Göttingen focuses on the basic principles underlying the complex interplay between lipids and membrane proteins in order to understand membrane processes at the molecular level [1]. This interdisciplinary approach will pave the way to address medically pressing questions, e.g. the understanding of how molecules such as drugs or neurotransmitters can pass the membrane barrier, which was just recently honoured with a Nobel Prize.
The aim of this contribution is to present a project plan on public outreach activities, which enables high school students to participate in this recent, interdisciplinary research in order to build a bridge between schools and universities. The students can deepen their acquired basic knowledge from chemistry and biology classes at school in lab practical at the university which can inspire them for science. In the development of teaching materials, the Model of Educational Reconstruction is applied, which is presented in some detail in the teaching unit "From Surfactants to Membranes". The model considers different perspectives including the analysis of content structure, perspectives of the learners and the development and evaluation of teaching and learning environments [2]. In this way, students can comprehend the construction and organization of biomembranes through an understanding of polarities and self-organization of surfactants. The significance of biomembranes as barriers for the separation of reaction areas will be proven by experiments on diffusion and osmosis. Finally, specific research topics will be presented using vivid models and videos ensuring that students will rediscover the fundamental aspects of self-organization, osmosis and barriers. Within this project, we work in close cooperation with teachers and we will develop additional learning materials, which will be enhanced and revised after the first experimental phase [3].

1. Background of the Project
In order to acquire a fundamental understanding of the function of biological membranes, it is essential to understand the complex interplay between lipids and membrane proteins. Thereby, a basis for medical research in issues like pharmaceutical transport and investigation of illnesses like epilepsy is given.
The Collaborative Research Centre (CRC) 803 "Functionality Controlled by Organization in and Between Membranes" has been funded by the Deutsche Forschungsgemeinschaft (DFG) since 2009 [1]. By the beginning of the second funding period (2013-2016), demands for an intensified outreach – *i.e.* a dialog between the public and scientists working at the CRC - arose. Amongst others, the aim of this public outreach program is to build a bridge between schools and universities and to provide an insight into the daily practice of interdisciplinary working scientists for students. Through this, students can understand the significance of natural scientific topics for society and can get inspired to pursue scientific studies [4].

Furthermore, a program for public outreach is presented, which was drafted for an annual volunteer lab course for high school students at the university and for upper secondary chemistry classes. The teaching unit 'From Surfactants to Membranes' will take up the current scientific discourse of the CRC in the context of experimental settings by an understanding of the relations between structure and characteristics of surfactants and membranes.

2. Collaborative Research Centre 803

The CRCs are research units at universities, which are created for a period of up to twelve years. Under the roof of a CRC, scientists work generally beyond the boundaries of their respective disciplines, institutes, departments and faculties as part of a comprehensive and scientifically excellent research program. Since 2009, the CRC 803 "Functionality Controlled by Organization In and Between Membranes" is administrated by Claudia Steinem (spokesperson) and Ulf Diederichsen (co-spokesperson). Its main aim is to elucidate basic principles underlying the complex interplay between lipids and membrane proteins in order to understand membrane processes at the molecular level. All projects mainly use tailored model membranes with defined and controllable lipid and protein compositions. With this unique approach, quantitative high-resolution (spatial and temporal) information is obtained to discover lipid and protein dynamics and the structural organization of membranes. One of the major goals is to derive general concepts for the self-organization of transmembrane peptide helices in lipid membranes as well as the structure-function relationships of water and ion-permeating channels. Furthermore, they seek to acquire a dynamic molecular view of membrane structures during the process of membrane fusion by unraveling the entire fusion pathway with the aim of establishing a link between molecular structures, lipid composition and mesoscopic membrane mechanics [1].

3. Biochemical Fundamentals of Surfactants and Membranes

Surfactants share the same structure: they consist of hydrophilic head groups and hydrophobic tail groups. Therefore, they are amphiphilic – one part of the molecule is soluble in polar solvents, the other part in nonpolar solvents and they prefer to adsorb at interfaces of heterogeneous systems (water/oil, water/air etc.). By building monolayers, surfactants lower the surface tension between two liquids. This phenomenon is used in washing processes in order to achieve a complete wetting of the clothes and to emulsify dirt particles. The nonpolar particles are covered by a thin layer of surfactant molecules so that the dirt will be dispersed in small micelles.

Cell membranes are bilayers composed of natural surfactants – mainly phospholipids. The amphiphilic character is constituted by the hydrophilic heads containing the negatively charged phosphate group and glycerol and the hydrophobic tails usually consisting of two fatty acid hydrocarbon chains. When phospholipids are exposed to water, they arrange themselves into a two-layered sheet (a bilayer) with all of their tails pointing towards the centre of the sheet.

In this way, reaction compartments inside the cell are separated from the cytosol and transport across the barrier of a lipid bilayer can take place through incorporated proteins. Molecules and ions can be transported through the membrane by channels (passive transport) and pumps (active transport). Hereby, biological processes like photosynthesis, cell respiration, generation of action potentials in neurons and signal transduction are enabled. Next to this, dynamic processes like fusion of membrane components and movement processes like migration, cell division and motility take place [5].

4. Concept for Public Outreach

In the context of a cooperative project between special branches of technical didactics and science, a teaching unit connecting high schools and the CRC is developed in order to provide an insight into scientific research and scientific studies to students. Thereby, scientific basics and current research

interests are closely connected. In this way, we illustrate future science perspectives to students and get them into first touch with the university.

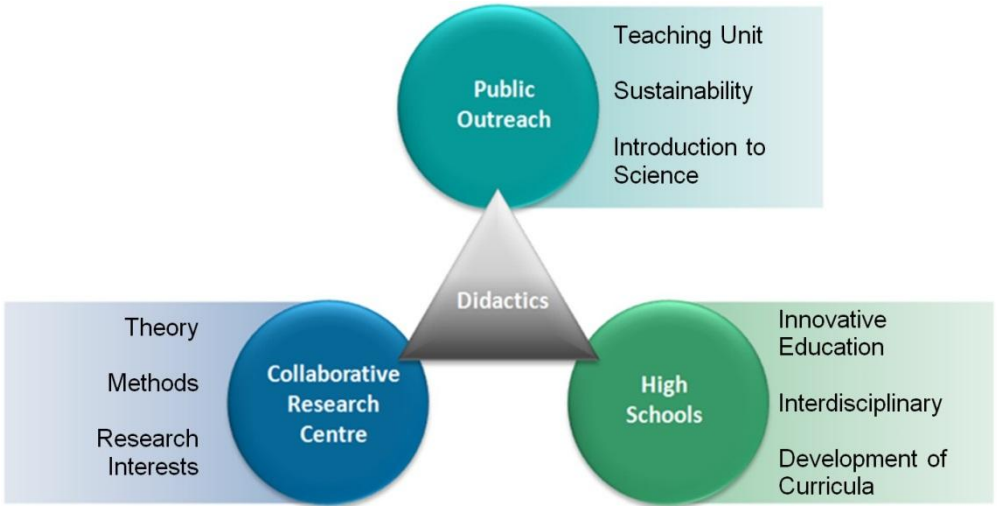

Fig. 1: Concept for public outreach (University@School) connecting CRC and high schools.

The teaching concept is based on the Model of Educational Reconstruction. This model is developed based on the teachers' theoretical understanding as well as the students understanding or difficulties of the subject matter. Analogous to this, a model for public outreach (Fig. 1), based on a close connection between the CRC and schools, was didactically constructed. Theory, methods and research interests of the CRC 803 were used for innovative, interdisciplinary education and for the development of curricula. Based on this connection, a sustained introduction to the science program for public outreach will be developed. The teaching unit "From Surfactants to Membranes" (Fig. 2) comprises experiments and teaching aids which should enable students to understand the relations between structure and characteristics of surfactants and membranes autonomously. Afterwards, they can deepen their knowledge through video-based introductions to experiments of the CRC. In this process, students recognize and describe principles like self-organization of surfactants forming micelles, vesicles, monolayers and bilayers as well as diffusion and osmosis through membranes.

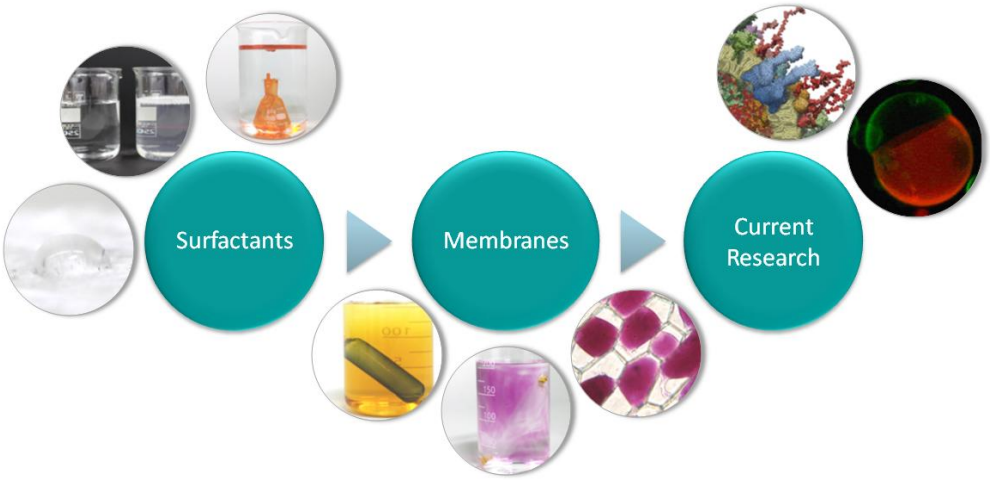

Fig. 2: The teaching unit “From Surfactants to Membranes” facilitates the relation between structure and characteristics of surfactants and membranes in order to provide an insight into current research of the scientists working in the CRC.

5. Examples for Experiments of the Teaching Unit

To illustrate the connection between structure and characteristics of surfactants and membranes, a multitude of experiments were developed. In the following, three experiments will be presented exemplarily. The experiments on surfactants cover topics like surface activity, solubility, surface tension, self-organization, the Tyndall effect, the detection of double bonds as well as their ability to emulsify and disperse. Key aspects of membrane experiments are diffusion, Brownian motion, osmosis, plasmolysis and cytolysis.

5.1 Surface Tension

The experiment shows how surfactants lower the surface tension at the interface of heterogeneous systems like water and oil. When soap is dropped onto the bounding surface, red colored oil pours out of the vessel until it is filled with water and small oil covered vesicles shift up. Analogous to biological systems, self-organization of a biphasic system aggregating to spherical particles takes place [6].

Fig. 3: Surfactants lower the surface tension at the interface of water and oil.

5.2 Self-organization of Octadecanoic Acid

Self-organization of surfactants can be demonstrated by the example of octadecanoic acid. The amphiphilic molecules are flexible in the liquified material and arrange themselves with their

hydrophilic carboxyl groups towards water and the hydrophobic alkyl tails on top. Therefore, water drops will roll off the hydrophobic top side of the crystallized octadecanoic acid slice and build flattened shapes on the bottom side. The shown principle of self-organization due to the polarity of substances can be used to give an understanding of the self-organization of biomolecules in membranes, which is currently investigated by the CRC. Furthermore, the amphiphilic character of octadecanoic acid is shown [7, 8].

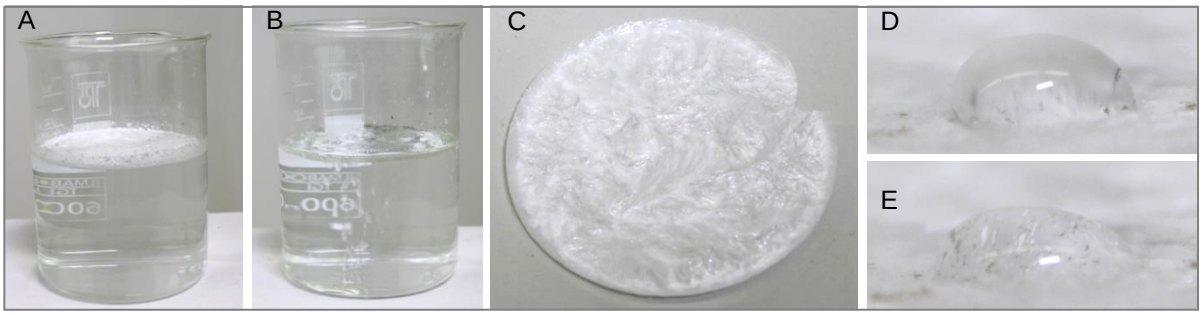

Fig. 4: Production of an octadecanoic acid slice. A) Solid octadecanoic acid. B) Liquified octadecanoic acid. C) Crystallized octadecanoic acid slice. D) Water drop on hydrophobic top side. E) Water drop on hydrophilic bottom side.

5.3 Gas exchange at membranes

Often, non-directional replacements of substances through membranes take place. For example, oxygen is absorbed and carbon dioxide is dispensed at the alveoli of lungs. The principle of diffusion of substances through a semipermeable membrane can be comprehended by the decoloration of phenolphthalein with sparkling water. Herein, carbonic acid and its corresponding species diffuse through the barrier of the dialysis tube into the phenolphthalein solution lowering the pH value below 8.2.

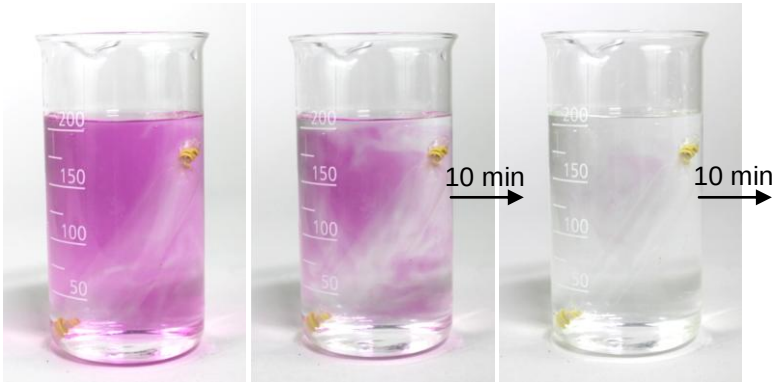

Fig. 5: Decoloration of phenolphthalein solution by diffusion of carbonic acid from sparkling water through a dialysis tube.

6. Outlook

The proposed teaching project is currently being implemented in a volunteer lab course for high school students at the Georg-August-University Göttingen, where grade 10 students from surrounding secondary schools participate in a practical course. The different chemistry departments as well as future perspectives for training, studies and profession in chemistry are going to be presented by the laboratories and interesting speeches. The volunteer lab course for high school students is taking

place annually. In addition to this, the teaching unit will be implemented in chemistry lessons of our universities' partner schools. The public outreach program will be evaluated by students, teachers and members of the university after a first testing phase and will be revised afterwards. To ensure the sustainability of the program, we aspire to establish a continuous dialogue between high schools and the CRC.

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