Anal Bioanal Chem (2011) 400:1533–1535
DOI 10.1007/s00216-011-4914-6

ABCS OF TEACHING ANALYTICAL SCIENCE

Learning chemistry—the Agnes-Pockels-Student-Laboratory at the Technical University of Braunschweig, Germany

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Published online: 30 March 2011

Introduction

In the last decade, an impressive number of student laboratories for natural science and engineering have emerged in Germany, mainly at universities and research institutions [1]. Several foundations have supported and promoted this development. The protagonists and sponsors of this trend were, inter alia, motivated by the fact that the number of first-year students in the so-called MINT subjects (MINT = mathematics, informatics, natural science, technical engineering) kept decreasing, that these subjects were not attractive for women, and that schools had limited possibilities for experimental work. In addition, chemistry, in particular, suffered from a poor and clichéd image. Public opinion had made an unconscious distinction between “good nature” versus “bad chemistry”—even though people happily adopted the progress in chemistry and material science in real life. Therefore, the projects were also initiated to increase public understanding of this science.

In the mid-1990s, Gisela Lück increased awareness for the fact that even young children can grasp chemical and physical phenomena [2]. In the 18th century, chemistry developed from an alchemical craft to a science, and even today it is—to a large extent—practical work. Chemistry deals with the properties and changes of matter and is therefore omnipresent in and around us. This means that it should be easy to interest children in chemistry.

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The Agnes-Pockels-Laboratory

The origin of today’s Agnes-Pockels-Laboratory goes back to 2002. Since then it has continuously grown and in 2010, approximately 3000 children and adolescents visited the laboratory (Fig. 1). Initially, it was intended to support teachers and contribute to better chemical education. Laboratory experiments for children in primary school were to bring children, especially girls, into early contact with laboratory work and enhance their self-perception and awareness with regard to their skills in natural science. At the same time, the project wanted to reach children before they were assigned to different school types at the age of 10 (a special—controversial—feature of the German school system). In the long run, these aspects are expected to contribute to equal opportunities. In contrast with many other student laboratories, the Agnes-Pockels-Laboratory does not focus on the short-term recruitment of new students, but wants to broaden basic knowledge in chemistry and create awareness of the omnipresence and relevance of chemistry in our everyday life.

The Agnes-Pockels-Laboratory receives school classes of all grades, lends experimental kits for various topics, invites weekly visits by children’s study groups, and offers advanced training for school and kindergarten teachers [3]. For the visits, the laboratory cooperates with the teachers to coordinate the experiments with the topics taught in school. Our objective is to support classroom education and to offer experiments that follow the regular curriculum.

Topics are, for instance, forensic chemistry (“Dem Täter auf der Spur”—“Solving the Crime”), food and nutrition, chemistry and magic, mechanical and biological sewage purification, air and combustion, salts and ions, electrochemistry, polymeric material, and renewable resources. We always focus on the phenomenon, e.g. the detection of non-distinguishable or non-visible compounds by distinct chem-

Fig. 1 Children experimenting at the Agnes-Pockels-Laboratory (with permission of Agnes-Pockels-Laboratory and TU Braunschweig, Germany)

ical reactions—precipitation, colour formation, gas development, chemiluminescence etc.—and include the issues of reproducibility and concentration-dependence. It is not our main intention to create a fun atmosphere or impressive effects, but to provide an interesting and stimulating setting. The equipment is simple; the experiments do not require advanced instrumentation—so it is "Barefoot Chemistry".

How to teach chemistry to young children without theoretical background? – At this point we have to remember that chemistry is a craft and that children learn by doing. Especially younger pupils are proud to work in a real laboratory with a laboratory coat, gloves, and protecting goggles on, using professional glassware, pipettes, spatulas chemicals, etc. They have to document their experiments and observations on a prepared instruction sheet—which is less popular than the hands-on work but it is also part of laboratory work. An important challenge is to translate what the eyes see into words; to exactly and completely describe the observations. That means not only to notice that a colourless solution has turned blue, but also whether it is still transparent or turbid. And, subsequently, to conclude that a clear solution means a soluble product, whereas a suspension indicates that the product has precipitated as a solid, insoluble compound. This helps not only to improve the knowledge in natural science, but also linguistic skills.

The experimental kits are a key component of our concept, because they can be used to extend the experimental work to the classroom. Teachers in primary schools, especially, make use of this offer as they do not usually have access to equipment and chemicals.

Weekly visiting study groups

There are always children that have a deeper, more serious interest in chemistry, and we are happy to be able to welcome them to the laboratory once a week. In 2007, we started with a group of 10 year old pupils. After each year, those who want to continue can join a group of advanced learners. The objective of this project—initially funded by the FCI (Funds of the Chemical Industry)—is to instruct the children in the fundamentals of scientific work. One question is, for example, what makes a pudding stiff? Hypotheses are collected, e.g. that the evaporation of water during cooking is responsible, experiments are planned to prove the hypotheses. Afterwards the conclusions from the observations are collected and discussed. In practice, this is not always a straight and successful process. Side ways open and are followed. The children like to prepare products, study their properties, e.g. a film of starch, testing its biodegradability, or the adhesive properties of the pasted starch they have prepared while studying the primary question. They will find out that an experimental set-up should not be too complex, which means they will heat starch with water, then sugar with water and then salt with water instead of mixing all ingredients, in order to finally be able to conclude which ingredient is responsible for the stiffening effect.

From big to small

Chemistry lessons in school usually advance very quickly to the subatomic level of matter, to electrons and protons, and stoichiometric relationships. This is far away from the macroscopic level which can be directly perceived, e.g. colour, stickiness, elasticity or brittleness, transparency (like ice), or turbidity (like snow). All these properties are the result of the molecular and supramolecular structure and order of the material. It therefore seems to be promising to proceed from "large" to "small"—from the macroscopic to the molecular level—and thus not to lose sight of the property–structure relationship. This could also help in the perception of chemistry (and physics) as basic principle(s) of the substantial world and of life, irrespective of whether materials are natural or artificial, instead of treating chemistry as an abstract and difficult topic.

Macromolecules are attractive candidates to test this concept. Depending on the functionalities of monomers, simple experiments can be used to obtain products with thermoplastic or duroplastic properties. The results can be interpreted with regard to the architecture of linear and crosslinked chains and macromolecular models can be introduced, even without knowing the type of chemical bonding involved. Gel formation of alginates and galactomannans by cooperative chain–chain interactions are further examples of nice and attractive experiments.

Who does the work?

Many of the student laboratories are the result of individual efforts. They are run by scientists, to a large extent without a solid background in pedagogics, together with less experienced students—with a high fluctuation rate. Financing is almost always a problem. There are hardly any permanent positions, and those responsible struggle from year to year to ensure the financial basis, submitting applications and proposals. In the Agnes-Pockels-Laboratory, eight women, chemists, biochemists, or food chemists—six of them holding a PhD and three students—currently work on an hourly-paid basis. The laboratory has until now been financed through various foundations, the Fund of the Chemical Industry (FCI) donations, and, since 2008, also by the university. In addition, the Ministry of Education of Lower Saxony finances a part-time (50%) primary school teacher. However, continuously raising the necessary money is a time-consuming burden for all of those who have been highly committed to this project over the years. It is probably not a coincidence, but rather symptomatic, that this work is mainly carried out by highly qualified women who at the same time raise a family.

Against this background it becomes clear that stable financing and a minimum number of appropriate positions would guarantee the future of the laboratory and increase the quality of the well established student laboratories. This should be the joint responsibility of the ministry of education and the ministry of science, because both schools and universities, and, finally, society also, benefit from these initiatives. The international year of chemistry would be a good opportunity for the governments of the federal states to set a milestone in this respect.

Who was Agnes Pockels?

And why was the Laboratory named after her? Agnes Pockels [4] was born in 1862, at a time when women in Germany were still far from being allowed to attend universities. However, during kitchen work she became so interested in surface tension phenomena that she developed a simple but efficient device, the Pockels' trough, which resembles today's Langmuir–Blodgett technique. As an autodidact she performed systematic measurements and gained pioneering results, which by support of the established scientist Lord Rayleigh were published in *Nature* in 1891. In 1932 Agnes Pockels received the honorary doctorate of the Technische Hochschule Braunschweig.

Outlook

After an enthusiastic start and plenty of pictures with bright-eyed children, student laboratories at universities have occasionally been criticized for focusing on experimental highlights with a high fun but low learning effect. Although this criticism may be true in some cases, there is a study by Christoph Pawek which shows that four German Aerospace Center (DLF) school laboratory locations in physics had a long-term positive effect on interest and on self-perception of abilities [5]. Future issues regarding natural resources and energy, climate, health and nutrition, all require basic knowledge in natural science and an increased awareness of the relationships in these interdisciplinary fields. In this context, student laboratories in the various fields can make an important contribution, now and in the future.

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