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FORMAL AND NON-FORMAL EDUCATION – NEW ENVIRONMENTS AND CONDITIONS

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Application of the Design of Experiments theory in laboratory classes for future science teachers

In the teaching of chemistry, at all levels of education, the most valuable methods are those in which learning occurrs through discovery (Lazonder, Harmsen 2016; Cheung 2011). Teaching chemistry should be a reflection of the research process and should be based on experiments performed by students (Sandi-Urena et al. 2011; Balim 2009). The Inquiry Based Science Education strategy based on a constructivist research cycle, also assumes, putting research hypotheses, planning experiments and their execution, collecting experimental data, and organizing and verifying them (Ctrnactova, Zamecnikova 2017).

Nevertheless, chemical teaching is dominated by 'chemical exercises' that are only a group of technical activities that lead to a specific effect. Students usually perform chemical exercises based on the diagrams and instructions given to them by the teacher. In Poland, students rarely have the opportunity to independently plan and carry out experiments, which in addition to performing manual activities also requires the experimenter's intellectual preparation and the ability to use the results of the experiment. Therefore, at the Pedagogical University of Cracow, it was decided to introduce a new subject "Designing Chemical Experiments" (DChEx). It is a course designed for science master studies – future teachers of biology and chemistry. The course is the opportunity for learning various aspects of planning scientific research process on the bases of planning chemical experiments. DChEx is the course that requires from students working alone from the beginning to the end. Moreover the course teaches the students how to cope with nonstandard problems and prepares them to solving complex tasks.

Description of the course

The course includes: 10 hours of lectures and 30 hours of laboratory work. The course is supported by materials on the Moodle platform (http://moodle.up.krakow.pl/course/view.php?id=114; password 'Planowanie'). The course is allocated with 2 ECTS points.

The lectures – theoretical part

During the lecture students will become familiar with DOE principles (*Design of Experiments*). DOE is a discipline of mathematical statistics that deals with data collection in a situation where the information obtained is accidental. A well-designed experiment allows us to judge the causal effects of interventions. The Basics of Modern Theory of Experimental Planning was interpreted by Ronald A. Fisher in 'The Design of Experiments' (Fisher 1996).
The main ideas of experiment design are:

- Comparison – In order to assess the effect of the intervention, it is necessary to compare the objects exposed to this intervention and objects exposed to it (the so-called control group).
- Randomization – Selection of units to be observed, exposed to different types of intervention, respectively, will be included in the control group, must be based on probability selection.
- Replication (multiple repeat) allows you to evaluate the random variability of the measured quantities and thus determine the accuracy of the measurements.
- Block design, stratification – The distribution of experimental units into blocks or layers that show similar properties will reduce the impact of variability sources that are not subject to investigation.
- Factorial arrangements – The experiment can examine the effect of several factors (different interventions) at a time, including their synergistic effects.
- Orthogonality – A factorial experiment should be designed to allow an independent assessment of each individual factor.

Laboratories – practical part

In this part of the course students must invent, design and then perform 10 different experiments and after that prepare documentation of those experiments. They basically work individually however they can cooperate, help and advise the rest of the students in the group and teacher. Each student is free to carry out any kind of experiment, however they have to follow some guidelines. Each experiment has to include at least three variable factors (students usually choose: temperature, concentration of reagents, material fragmentation, type of substance) which should be changed five times. This gives us 125 cases to explore! Because it is not feasible to perform them during 3 hours of laboratory classes – students must apply the DOE principles.

Usage of the DOE rules are not the only requirement to pass the course. The student should design his experiments using different techniques of executing the experiments. The individual techniques are described in detail below.

Description particular techniques

The main goal of the course is to teach students how to independently plan chemical experiments and perform independent research. However, each of the aforementioned 10 techniques has its own additional purpose.

The first experiments carried out by students in the laboratory are so-called '**home experiments**'. They are simple experiments that do not require specialized laboratory equipment and reagents are available in the household (for example foodstuffs, cleaning products, medicines, etc.). The aim of these laboratory classes is to familiarize students with the practical application of the DOE theory – in a simple situation known to them from everyday life.

The second laboratory classes are experiments in **SSC** (small scale chemistry) or **MCE** (microscale chemistry experimentation). This method consists in conducting chemical experiments using small amounts of solid substances (several dozen to several hundred mg) and small volumes of liquid (up to approx. 1 cm^3). It is characterized by the fact that during the performance of experiments the used equipment deviates from the standard equipment, techniques known among others from microbiology are used. The aim of these classes is to draw students' attention to environmental protection and remind them of the rules of green chemistry. During these laboratory classes, students change traditional chemical experiments for experiments in SSC or MCE.

Drop (touch) analysis is also a kind of MCE experiments. In this case single drops of test solutions are used, therefore, reactions must be very sensitive. Drop analysis is not performed in tubes but on filter paper and also on laboratory plates, foil or other substrate. The purpose of these exercises is to guide students to the 'drip analysis' technique. And to draw attention to how you can replace the classic chemical reactions in test-tubes with 'drop' reactions. Most often, students use this technique to plan experiments on topics: analysis of cations and anions, pH test, precipitation reactions, paper chromatography.

Experiments under a microscope – the microscope is commonly associated with biology research and the basic application of a microscope in chemistry is the observation of the shape of crystals of chemical compounds (i.e. using it in crystallography). Currently, however, it is increasingly used as one of the MCE methods. In this case, the course of the chemical reaction (and the formation of crystals) is observed directly under the microscope. Students most often perform: reactions of formation of sediments and reactions of metals with salts.

Application of the **overhead projector** or **visualizer** to visualize the course of the reaction, allows you to show chemical reaction for greater number of recipients (e.g. students), without using a macro scale, or allows you to take good quality photos documenting the course of the experiment. In this case, the reactions take place in Petri dishes. The same chemical reaction looks different when we use test tubes or Petri dishes. Although the reaction mechanism is the same, when we use Petri dishes we can also observe physical phenomena (e.g. diffusion). In this case, the students' favorite experiments are the reactions of precipitating the sediments that they call 'jellyfish'. (We pour water into the Petri dish; on the opposite sides of the dish, we add some salt e.g: Na_2CO_3 and $MgSO_4$; observe the nascent sediment – it looks like a jellyfish!)

Experiments in a microwave oven shows students how microwave heating can be used instead of traditional heating with a burner. The use of microwaves affects the acceleration of chemical reactions and has a positive effect on the efficiency of

the reaction. It also change the reaction conditions – e.g. use of diluted acids instead of concentrated ones. This technique allows in many cases to conduct experiments in accordance with the principles of green chemistry. Students use a microwave oven mainly for reactions in the field of organic chemistry, but sometimes they use it for reactions in the field of inorganic chemistry or to perform the so-called **home experiments**. Currently, microwaves are often used in organic synthesis – in this exercise students gain experience in using microwaves in chemistry and prepare for the future work of the researcher.

Experiments with using sensors and probes (we use Vernier sensor). Sensors enable automatic recording of measurements performed during a chemical experiment, therefore students do not have to perform tedious manual measurement registration. Thanks to this, students can focus on the chemical aspects of the process and in the final stage on the interpretation of the results. Nowadays, most researchers use computer sensors, so the ability to apply them to research planning is very important for students. In their research, students use temperature sensors, pH and visible spectrum sensors.

There are two ways to use the **Internet to simulate chemical experiments**. The first is the use of existing on-line laboratories (e.g. http://www.chemcollective.org/vlab/vlab.php, http://www.virtlab.com/, http://www.onlinechemlabs.com/, https://phet.colorado.edu/cs/, https://latenitelabs.com/chemistry/) and proposing simulations of experiments that can be carried out in them. In online laboratories, the selection of reaction substrates and setting the reaction conditions and viewing the animation of the reaction takes very little time. Therefore, the student can perform many online experiments in a short time. The main advantage of online laboratories is that the student on his own chooses reaction substrates and reaction conditions – this increases the students' inventiveness and also increases their activation and motivation. Another advantage of online laboratories is that each student designs and performs virtual experiences themselves, which results in the individualization of teaching. Online laboratories also ensure students' safety. Students can perform such experiments online that are dangerous in the real world.

The second possibility of using the Internet for the presentation of chemical experiments is the use of existing films from chemical reactions (e.g. from YouTube). Students using existing movies and computer programs (e.g. MovieMaker, LearningApps or EDpuzzle) create a coherent experiment with research questions.

Shows – experiments for XXL scale – currently, 'chemical reaction shows' are a permanent element of museum exhibitions, "Open University Days" or "Science Festivals". Because the experiments' demonstrations are aimed at encouraging the study of natural science that is, they must be effective. Therefore, students should be able to do this type of experiment. For 'show' type experiments, particular attention should be paid to health and safety rules.

Planning outdoor research. Outdoor research is a return to the roots of the natural sciences. Initially, the world around us was studied and described in field, and then the research were 'moved' to laboratories. Until today, some research cannot be done differently than by taking samples from field tests. Soil research, clean air or

water – these are typical field (outdoor) studies. Students should be able to plan and perform this type of research.

Summary

The classes "Designing Chemical Experiments" allow students not only to become familiar with the theory of DOE but also to learn how to apply this method in practice. Various experimental techniques cause that laboratory classes are not boring – students highly appreciate the satisfaction of these activities. In addition, the ability to plan experiments as well as to perform them with different techniques is necessary for a chemistry teacher.

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Abstract

The article describes innovative classes for biology and chemistry students – future teachers. The classes "Designing Chemical Experiments" comprise of ten hours of lectures and thirty hours of laboratory classes. During lectures, students become familiar with the theory of DOE. During laboratory classes, however, students apply the DOE theory in practice. As part of the course, students must independently plan 10 chemical experiments and then perform the experiments they plan themselves. During laboratory classes, students also practice various experimental techniques from microscale to macro scale.

Key words: DOE theory, Designing Chemical Experiments, laboratory

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