EMPLOYMENT OF SUITABLE DEVICES AND PREPARATION OF EDUCATIONAL MATERIALS FOR PHYSICAL CHEMISTRY EDUCATION AT HIGH SCHOOLS

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Abstract

The education of physical chemistry at Czech schools is rarely supported by corresponding experiments and hardly any of them reflects the real-life laboratory and industrial practice, where a large scale employment of devices and applications based on physical chemistry methods and phenomena is typical. For example, various types of methods based on interaction of light and matter are widely used for analysis in science and industry (UV VIS, Infra-Red, Atomic Absorption Spectroscopy etc.) and in various commercial applications (optical devices). Plenty of analytical and commercial applications are based on electrochemical phenomena (pH measurements, ion selective electrodes, dry cells etc.). Therefore, it is necessary to introduce the physical chemistry phenomena and related experiments supported by appropriate devices and methods in high schools chemistry curriculum. However, for majority of high schools in the Czech Republic, the price, space requirements and necessity of trained staff are limiting factors for employment of these devices and experiments in physical chemistry education. Solution of the problem is searching for such devices which are relatively cheap, modular, multifunctional and user-friendly with cheap and easy servicing and creating the experiments and educational materials which reflect the phenomena and applications mentioned above.
To fulfill the task, spectrometer Ocean Optics USB 2000 and multifunctional device Pierron Infraline Graphic have been employed as suitable devices for preparation and testing of variable educational materials and experiments which are focused on introducing the spectroscopy and spectroscopic methods as well as other methods based on physical chemistry phenomena (pH, conductivity) into high school chemistry curriculum. There have been proposed, prepared and tested the educational materials suitable for high school, including PC presentations (MS PowerPoint, OOo Impress), educational texts and work-sheets describing experiments. These are, for example, qualitative and quantitative analysis of dyes in various foods and drinks, natural dyes in herbs, shortened analysis of water (Cl^-, NO^{3-}, pH measurements, and conductivity).
Keywords: *absorption spectroscopy, instrumental experiments at high schools, Ocean Optics USB2000, physical chemistry education, physical chemistry presentation, Pierron Infraline Graphic.*

Introduction

The educational system in the Czech Republic has recently undergone a variety of changes connected with implementation of Framework Educational Programmes (FEP) (Institute of Educational Research, 2006; Ministry of Education, 2004), which were suggested and formed as a result of Lisbon meeting (Directorate-General for Education and Culture, 2001). This process should improve the quality of education in the Czech Republic and change a way of education from learning numerous definitions and theorems to ability to find information, read and extract important information from text, ability to understand relation to practice and common life and see the multidisciplinary connections etc. (Institute of Educational Research, 2006; Ministry of Education, 2004). A problem accompanying the implementation of FEP into high school curriculum is a lack of suitable educational materials. Thus, a pressing need for educators in the Czech Republic is a preparation and an evaluation of new educational materials which correspond to requirements of FEP as well as reflect today world. On the other hand, it is a good occasion to improve existing educational materials and place new themes which were missing in high school curriculum so far although they have played an important role in the recent world.

The phenomena of physical chemistry can be mentioned as an example of such area and/or theme. The physical chemistry is a typical example of multidisciplinary branch which covers phenomena important in chemistry and biochemistry, physics, geology and biology. For example, various types of methods based on interaction of light and matter are widely used for analysis in science and industry (UV-VIS, Infra-Red, Atomic Absorption Spectroscopy etc.) and in various commercial applications (optical devices). Plenty of analytical and commercial applications are based on phenomena of electrochemistry (pH measurements, ion selective electrodes, dry cells etc.). Therefore, it is necessary to introduce the mentioned physical chemistry phenomena and related experiments supported by appropriate devices and methods in high school chemistry curriculum. Unfortunately only a few chemistry phenomena are taught at high schools in the Czech Republic. The reason might be that teachers don't have appropriate support or devices for demonstration of experiments typically performed in laboratory or as demonstrational in a class in front of students. Moreover, for majority of high schools in the Czech Republic, the price, space requirements and necessity of trained staff are limiting factors for employment of these devices and hence experiments in physical chemistry education. For example, in the case of spectroscopic measurements, a suitable device is usually expensive and it needs a well trained staff and care, it must be placed in laboratory at suitable position etc. Solution of the problem is searching for such devices which are relatively cheap, modular, multifunctional and user-friendly with cheap and easy servicing and creating the experiments and educational materials. At the Czech market, there are several suitable devices which fulfill the noticed requirements. Especially, the older systems as ISES or IP Coach (Bílek et al., 1997; Bílek et al. 2005) can be mentioned as well as newer SM System or Infraline Graphic (Skoršepa et al., 2006; Stratilová Urválková et al. 2007). These devices allow connecting a variety of sensors related to chemistry, physics and biology - pH sensor, conductivity sensor, colourmetric sensor, resistance sensor, and a lot of others (Pierron, 2004) – which can easily support, through appropriate experiment, teaching process.

Objectives and methodology

This contribution is focused on preparation of new educational materials considering spectroscopy as an integral part of physical chemistry with emphasis on requirements of FEP currently introduced at high schools in the Czech Republic. The reason is importance of phenomena connected with interaction of light and matter as well as physical chemistry phenomena for recent scientific, analytical and "real world" applications.

To fulfil the teachers need for corresponding materials, there were suggested to be prepared the educational materials covering multimedia presentations prepared in Microsoft (MS) PowerPoint and OOo Impress format, an educational text for teachers, its simplified version for students, a set of laboratory spectroscopic experiments and tests. The form of presentation was chosen due to increasing number of data-projection devices in Czech high schools as well as due to didactic possibilities of this way of education (animations, motivation figures etc.). The ppt format has been selected because MS PowerPoint is the most extended presentation program at high schools in the Czech Republic; nevertheless, all the educational materials have been also converted to OOo Impress presentation format for those who prefer free software solution for their presentations. Preparation of educational text has been also suggested. Substantial attention has been focused on proposition, treatment and testing of experiments targeted on spectroscopy and additional measurements. All the experiments has been tested with accent to be easy to perform, clear and reproducible.

Employed software and devices

For preparation of educational materials, software of Microsoft Company, Redmont, USA was employed. Microsoft Word XP was used for preparation of educational texts and Microsoft PowerPoint for preparation of the presentations. OriginPro v. 7.5 of OriginLab Company, USA was used for preparation of graphs and charts. Software Che3Wind of SoftShell Company, France, and ACD/Labs Chemsketch, ACD Labs, Canada was employed for drawing of chemical structures, schemes and apparatuses.

The experiments were performed and tested using Ocean Optics USB 2000 UV-VIS spectrometer operating together with OOIBase 32 software (Ocean Optics, Netherlands) or Pierron Infraline Graphic multifunctional device operating together with DidexPro software (Pierron, France).

Educational materials – presentations, educational text and tests

A variety of educational materials focused on spectroscopy have been prepared. They consist of three multimedia presentations prepared in Microsoft PowerPoint and OpenOffice.org formats, an educational text for teachers and students, a set of 12 laboratory spectroscopic experiments (described in worksheets in teachers and students version), 3 tests and manuals and presentations on treatment with employed spectrometer.

The first presentation is focused on basics of spectroscopy. It consists of 28 slides covering definition of spectroscopy, its importance and employment, basics of interaction between light and matter, definitions of absorption and emission of light, explanation of term spectrum and its significance for qualitative as well as quantitative analysis, Lambert-Beer law, explanation of fundamentals of light and of color of substances and, finally, the scheme, function and the most important parts of UV-VIS spectrometer. The second presentation deals with dyes included in foods. It is divided into parts related to natural dyes and dyes prepared synthetically. It also describes division of dyes into groups on a basis of their chemical structure. The presentation also contains basic information about the most widely used dyes in the Czech Republic (chemical formula, examples of food, where the dye can be found and UV-VIS spectrum of the dye). In addition to that, the presentation deals with E-codes employed to mark various food additives. The third presentation is, in fact, an operating manual for USB 2000 UV-VIS spectrometer employed for spectroscopic experiments described in *Materials for experiments focused on spectroscopy* section of this contribution. It is focused on assembly of this modular spectrometer as well as its control through OIIBase 32 operating software. All the presentations were prepared in Czech as well as in English version.

The education text consists of 14 pages of text including 16 figures and it is targeted on the same areas as a mentioned presentation on spectroscopy, however, it deals with the mentioned themes in more detail than the presentation. It should be a “quick study guide” for teachers to clear or understand the themes in presentation as well as for students who wish to learn more about spectroscopy. The text is now only in Czech language version.

Three prepared testing sheets involved a set of 9 questions or problems. All the questions or problems have been focused on testing of themes mentioned in the presentations or in the educational text. The accent has been placed on treatment of spectra from qualitative as well as quantitative point of view and Lambert-Beer law supplemented with questions targeted on dyes and basics of spectroscopic measurements. The tests have been prepared in Czech and English language versions.

Materials for experiments focused on spectroscopy

A set of 12 experiments targeted on spectroscopy was prepared, tested and evaluated. The experiments were prepared with regard to price and availability of materials and chemicals to make the experiment as cheap as possible. For some quantitative measurements, Pierron Infraline Graphic multifunctional device with a colorimetric sensor can be employed.

Despite its simple construction (Figure 1) and low price (ca 25 Euro per sensor, however, the Pierron Infraline Graphic device is also needed for the experiment), it provides sufficient results for demonstration of light absorption phenomena as well as for demonstration of Lambert-Beer law

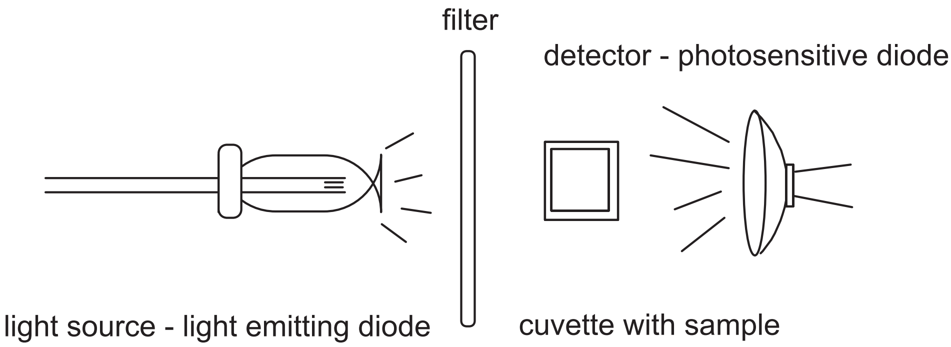

Figure 1. Scheme and principle of colourmetric sensor for Infraline Graphic device.

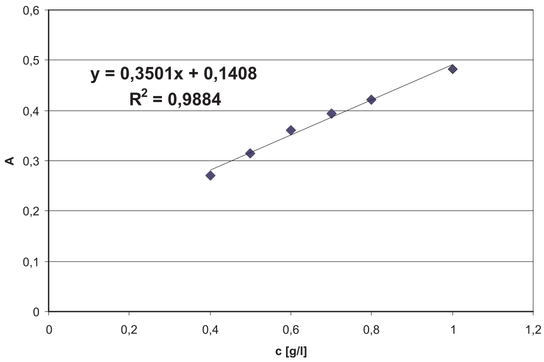

Figure 2. Calibration curve for determination of Allura AC food dye concentration - use of Lambert-Beer law.

Figure 3. Processing unit of spectrometer Ocean Optics USB 200 UV-VIS.

(Figure 2). On the other hand, the experiment performed with this device is limited by the number of colorimeter disks (filters) and their quality and properties. In addition to that, the full spectrum is not measurable with this device. Hence, for the more complex and more visual experiments, the spectrometer Ocean Optics USB 2000 has been selected. It consists of light source, cuvette holder and processing unit, all connected via optic fibers. The processing unit (Figure 3) is controlled through the computer via Ocean Optics OIIBase 32 operating software. The computer is linked with processing unit through standard USB interface. The spectrum is measured quickly (sufficient acquiring time is about 1 – 5 seconds) and at once (Figure 4), thus, terms spectrum and light absorption can be easily demonstrated to the students. The advantages of this spectrometer are reasonable price (ca 1000 Euro) for processing unit for measurement in visible (VIS) region (ca 1000 Euro), simple control, modularity and minimal space requirements. Additional expenses can arise from buying the light source and the cuvette holder, which are sold separately. However, a standard halogen lamp can be used instead of a commercial light source. Although the stability of halogen lamp spectrum is not perfect in the case of non-commercial light source, it is sufficient for demonstration of mentioned phenomena. The commercial cuvette holder can also be easily substituted by wooden holder or by any solution, which fix the cuvette in a stable position. Due to its dimensions and quick response, the USB 2000 spectrometer is a suitable device for demonstrational experiments.

Proposed and tested experiments are mostly targeted on qualitative and quantitative determination of dyes in food and plants in VIS region, nevertheless, one experiment, *Analysis of content of quinine in Tonic* has to be done in UV region. In the case of food or plants which are colored by a mixture of dyes, the students are required to separate the individual dyes by chromatography methods or electrophoresis and to compare the spectra of individual dyes with a spectrum of mixture.

The following experiments have been proposed and tested: *Try to find the corresponding spectra* – students are required to measure the spectra of anonymous food dyes and then find the corresponding

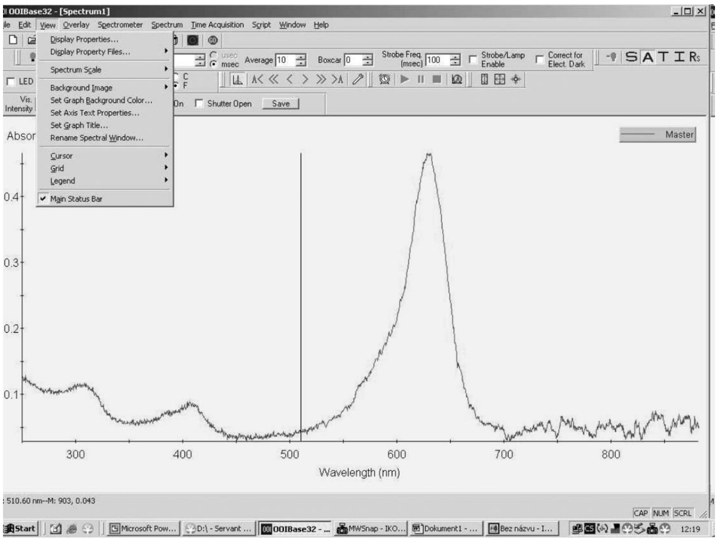

Figure 4. UV-VIS spektrum of brilliant Blue FCF measured by USB 200 UV-VIS spectrometer using OII Base 32 operating software.

spectra of standards to identify the dye. The experiments focused on identification of dyes in sweets are similar: *Try to identify the dyes in jelly bears* and *why are some sweets so colorful?* Identification of dyes on a basis of comparison with spectra of standards is also employed in experiments *Analysis of carotene dyes in fruits and vegetable*, *Analysis of green parts of plant* and *Analysis of mixture of food dyes*, however, the separation of the dyes by column or thin layer chromatography or by electrophoresis is required. In experiment *Influence of pH on structure of natural and chemically prepared acid-base indicators*, the change of the structure of indicator and corresponding change of the color and spectrum are discussed. The remaining experiments are based on employment of Lambert-Beer law and determination of content of various food dyes etc.: *How much are drinks colored? Analysis of content of quinine in Tonic, Check the producer! – analyze the content of iron ions in Ferronat retard drug and compare with drug brochure* and *Analysis of proteins in eggs and jelly.* The experiment *Analysis of water* focused on shortened analysis of water is more complicated. It is performed with Pierron Infraline Graphic device and a variety of sensors - conductivity sensor (conductivity of water, determination of concentration of Cl^- ions), pH sensor (pH of water, determination of buffer capacities) and colorimetric sensor (determination of concentration of NO_3^- ions).

For all the experiments, the worksheets were treated in student's and teacher's version. Student's version contains principle of the experiment and interesting information, which plays a motivation role, followed by materials and equipment needed and the information how to perform the experiment. The worksheet is completed with a part requiring evaluation of measured data and few questions related to measurement. Students are also required to make a short conclusion of their measurement. Teacher's version is supplemented by an overall information about the experiment as type of experiment, its duration, difficulty, short characteristics, objectives, related themes and phenomena, keywords, possible modifications, possible results of the experiment, method of its evaluation, answers to questions and notes and possible difficulties and problems, which can be encountered during the experiment. Finally, they are attached the references, which helped to authors to prepare the experiment or can be useful to teacher or to student to gather new or additional information.

Preliminary testing of materials at high schools

The prepared materials including few experiments were preliminary tested in a group of 36 students of V.-VII. classes of eight-year gymnázium (students 16-18 years old) at Gymnázium Josefská, Prague, Czech Republic during a regular lessons and laboratory classes. Due to low number of students, the results of testing are necessary to be considered as "non-statistical". On the other hand, the results of the testing showed some interesting features.

The group of students visited two introduction lessons focused on spectroscopy and food dyes of duration of 45 minutes where the mentioned presentations were employed. The education process was supported by the educational text on spectroscopy and student's version of worksheets for laboratory class, which were distributed among the students for study at home. In a laboratory, the students performed an experiment assigned, one related to qualitative and one to quantitative analysis. Finally, the students tried to pass one of the three tests. The results were a part of their overall classification. Hence, the students were motivated to pass the test. The rating of the test result was following: 0 – 4 points = rating *5* (the worst), 5 – 6 points = rating *4*, 7 – 9 points = rating *3*, 9 – 10 points = rating *2* and 11 – 12 points = rating *1* (the best). To pass the test, to acquire minimum of 5 points was necessary.

The evaluation of the results of the test showed that all the students passed the test and majority of them were rated better than *3* (Figure 5). That is why we speculate that materials can be possibly suitable for high school education. More detailed evaluation as well as experience from laboratory classes showed that the experiments focused on quantitative analysis are more difficult for students than the experiments on qualitative analysis. The problems are not mostly caused by experimental difficulties, but students have problems with evaluation of data using computer and problems with treatment of equations, although they passed the related courses in mathematics and computer skills

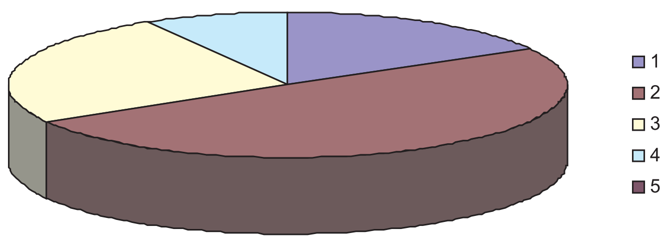

Figure 5. Results of test on spectroscopy.

(MS Excel etc.). Due to mentioned problems, it seems to be suitable to add to the presentation for the introduction lessons parts focused on treatment of measured data like construction of calibration curve, linear functions basics etc. The preliminary preparation of standard solutions can also help to students to focus on spectroscopic aspects of experiment. On the other hand, the students mastered evaluation of the spectra for qualitative analysis and answered the questions related to food and plant dyes.

Overall, the students were taken aback with a practical importance of spectroscopy as well as of its possibilities for analysis of food dyes that they encounter everyday. They did the experiments with passion and with vision that they learn more about the foods which they eat.

Conclusions

A set of educational materials targeted on spectroscopy was prepared with emphasis on requirements of Framework Educational Programmes (FEP). They contain three presentations, educational text, set of 12 experiments and 3 tests. The materials are in Czech language, however, presentations and tests were also prepared in English version.

The materials were preliminary tested in a group of 36 students. Preliminary testing showed that spectroscopy can be attractive for students, especially after emphasized applications of method and connection to the "real world". Testing also showed inadequacies in mathematic and computer data evaluation knowledge of students.

The experiments were designed to be performed using Pierron Infraline Graphic device and Ocean Optics USB 2000 spectrometer. Both the devices seem to be suitable to perform the experiments in laboratory classes or for demonstrational experiments due to their small dimensions, price and easy control.

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References

Bílek, M. et al. (1997). Školní chemický experiment s využitím počítače (Chemical experiment in School with employement of computer). *Chem. Listy 91*, 1074.

Institue of Educational Research. (2007). *Rámcový vzdělávací program pro gymnázia RVP G (Framework Educational Programmes for gymnasia).* Retrieved May 28, 2007, from the Framework Educational methodical Web site: http://www.rvp.cz/soubor/RVPG.pdf

Ministry of Education, Youth and Sports of the Czech Republic. (2004). *National Report of Development of Education.* Retrieved May 28, 2007, from:
http://www.ibe.unesco.org/International/ICE47/english/Natreps/reports/czechrep.pdf

Directorate-General for Education and Culture (2000): *Report from the Education Council to the European Council*. Retrieved May 25, 2007, from:
http://ec.europa.eu/education/policies/2010/doc/rep_fut_obj_en.pdf

Skoršepa, M. (2007). *Počítačom podporované chemické experimenty (Chemical experiments supported by computer)*. Retrieved May 28, 2007, from:
http://www.fpv.Umb.sk/kat/kch/skorsepa/index_s.html

Stratilová Urválková E., Šmejkal P., Čtrnáctová, H. (2007). Infraline Graphic – Multifunctional Data Collection Instrument for Physical Chemistry Education. *Annals of Polish Chemical Society* - accepted.

Pierron Prague. (2004). *Pierron Infraline Graphic - User´s manual* [Brochure].

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