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New Approaches
Нови подходи

INTERDISCIPLINARY PROJECT FOR ENHANCING STUDENTS' INTEREST IN CHEMISTRY

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Abstract. A student research project for sampling and analysis of drinking water from different Bulgarian regions has been parallel incorporated into analytical and organic courses at the second level of high engineering education in Bulgaria. The degree of quality of drinking water has been evaluated in five cities from different Bulgarian regions: Stara Zagora, Gorna Oryahovitsa, Parvomai, Dupnica and Sofia. The students analyzed water samples for pH, hardness, organic compounds, sodium, potassium and heavy metals ions like cadmium, copper, iron, lead and manganese using titrimetric methods, atomic absorption and atomic emission spectrometry, potentiometry and voltamperometry. The article also describe pre-lab activities related to the "water quality project" in order to increase student motivation, independence, and critical thinking skills. Students have been motivated to perform the seminar and practical work and get used to an approach often used in the chemical engineering' practice. Students have been explored parameters concerning water quality from different sources and had an opportunity to evaluate the data critically and to answer the pre-lab questions. Based on student results the "water project" became overwhelmingly popular with students while challenging them to think critically and work independently on problem solving tasks. Thanks to the "water quality project" we found that the student's willingness to carry out a scientific work is increased. The students become more motivated and committed to the learning process.

Keywords: problem solving, drinking water project, analytical chemistry, organic chemistry

Introduction

Laboratory classes often have a wide range of learning objectives including an understanding of theory and calculus, an improvement of manual skills and time management, as well as the capability to collect and interpret data (Hofstein & Lunetta, 2004; Staver, 2007) As a result, students are often overloaded. Furthermore, it is often found that students come to classes totally unprepared. Hence, they are often found to follow lab manual procedures without understanding the context of the experiment and thus without learning anything. Therefore the pre-lab exercises are important to encourage the students in the learning process (Bulte et al., 2006; Schallies & Eysel, 2004). Good laboratory and practical work combining with pre-lab strategy can also help students develop expertise in critical enquiry, problem solving, experimental design, data analysis and presentation, and a long list of important academic and professional abilities. Some forms of pre-laboratory class exercises (pre-labs) are beneficial in circumstances (Richter-Egger et al., 2010). Students are forced to engage with the material before the lab, so they know what they are doing and why. Other pre-labs are in the form of short questions, sample calculation or quizzes (Peteva et al., 2014). Students are asked to draw a flow chart of the experimental procedure or to look for health and safety regulations about chemicals. Unfortunately pre-labs are not currently used in the chemistry teaching labs in engineering education of analytical and organic chemistry in University of Chemical Technology and Metallurgy in Bulgaria. The practical classes in a basic courses (organic, inorganic and analytical chemistry) are "traditional", namely the students just follow the instructions and thus gain some experimental experiences. Educational research indicates that traditional laboratory activities often fail to engage students in the discussion and analysis of main ideas and do not effectively promote the development of valued science practices (Xu & Talanquer, 2013; Lunetta et al., 2007; Singer et al., 2006; Psillos & Niedderer, 2002; Lazarowitz & Tamir, 1994).

We think that the students could be motivated to learn in the laboratory context if they can feel a spirit of excitement when investigating a scientific phenomenon, or when creating something that actually works. There is an increasing demand from students to make what they study more "relevant", so this may have a positive impact. The water quality study has been motivated students to identify and apply research concepts, work collaboratively and communicate effectively in the labs (Richter-Egger et al., 2010; Arnold, 2003; Juhl et al, 1997; Latch, 2014). The students have been explored different decisions and argued for the method, which they have preferred for their further experimental work. The integration of student research into a general chemistry show that students believed they are doing work similar to a research scientist, that they appreciated this opportunity to do research, that it increased how much they like science in general, and that they are more likely to consider specializing in chemistry (Richter-Egger et al., 2010).

Because of water is a substance that can contain different types of compounds it is subject to analysis of analytical, organic and physical chemistry. The quality of the drinking water is vitally important but it often easily degraded. The major categories of impurities in water are micro-organisms, pyrogens, dissolved inorganic salts, dissolved organic compounds, suspended particles and dissolved gases. Metals like aluminium, calcium, cadmium, chromium, copper, iron, lead, magnesium, manganese, zinc etc. may occur in drinking water due to geogenic reasons or may be due to anthropogenic activities such as uncontrolled discharge of waste waters of different types of industries. Some of the metals in the higher concentrations i.e. more than permissible limit are toxic for human beings. Higher concentrations of these metal ions result in to several types of human health problems (Farid et al., 2012; Sharma & Tyagi, 2013).[1)] The "water quality projects" known in the literature have not reported the engaging student to collect drinking water probes from different regions and to motivate them to develop an experimental strategy based on equipment and time available to analyse these water probes in two parallel disciplines in the chemical engineering education.

And then? - How can we get our students to think and to be more motivated in the learning process? – A question asked by many faculties, regardless of their disciplines. Therefore our central goal was to make the pre-labs as fundamental part of laboratory classes parallel in two disciplines (analytical and organic chemistry) in second year of high education; a part of a process used to increase the responsibility of the students for their own work, and to prepare them for future situations in which they will take complete responsibility.

Research goals

The purpose of this study was to integrate the pre-labs into analytical and organic chemistry course at the second level of high engineering education in University of Chemical Technology and Metallurgy in Bulgaria. We also had the idea to combine and integrate the topic "water quality problem" in two chemical disciplines in order to give much more attention to the teaching, and hence the engineering students' learning process. During the courses of analytical and organic chemistry the students were tested the drinking water pollution in several regions of Bulgaria (Fig. 1). A form of assessment was included to ensure that students do the pre lab exercises and that they see the pre-labs as an integral part of whole practical assignment.

Discussion

Analytical and Organic Chemistry are just a part of disciplines which are basically for the chemistry in University of Chemical Technology and Metallurgy-Sofia. The analytical chemistry training is in two semesters of one academic year. First, the students learn the basics of the analytical chemistry, chemical equilibrium and the methods for quantitative components determination by titrimetry and gravimetry. The second semester is mainly devoted the instrumental methods for qualitative and quantitative components determination.

Organic chemistry enables students to become familiar with compounds and reactions taking part in different technology processes and organic compounds that have importance in pharmacy. The students also learn the basics of the organic chemistry - study of the structure, physical and chemical properties, and reactions of organic compounds, i.e., matter in its various forms that contain carbon atoms, parallel with the course by analytical chemistry in two semesters. Seminars and

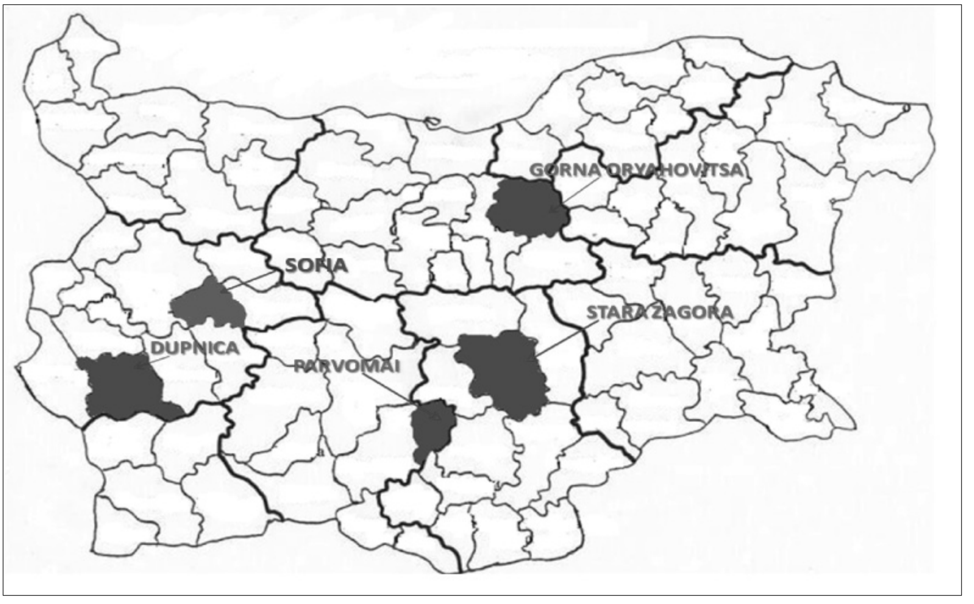


Figure 1. Map of Bulgaria with the studied regions for "water quality problem" (dark areas)

laboratory practices are complementary to lectures. Therefore the implementation of project in both disciplines is convenient and possible. Moreover, the two disciplines are the main part of second year engineering high education. Fig. 2 presents the correlation between the different chemical disciplines according to the "water project".

The students in lab in second year chemical engineering education are divided in groups of seven to fifteen students. For "water quality problem" study the students from each group were divided into smaller groups of three to four students in the class that analyze water samples from different regions of Bulgaria for a particular chemical species using different methods. Each team was presented with a "water quality problem" (Table 1) that they working together to solve over the analytical and organic course of one education year.

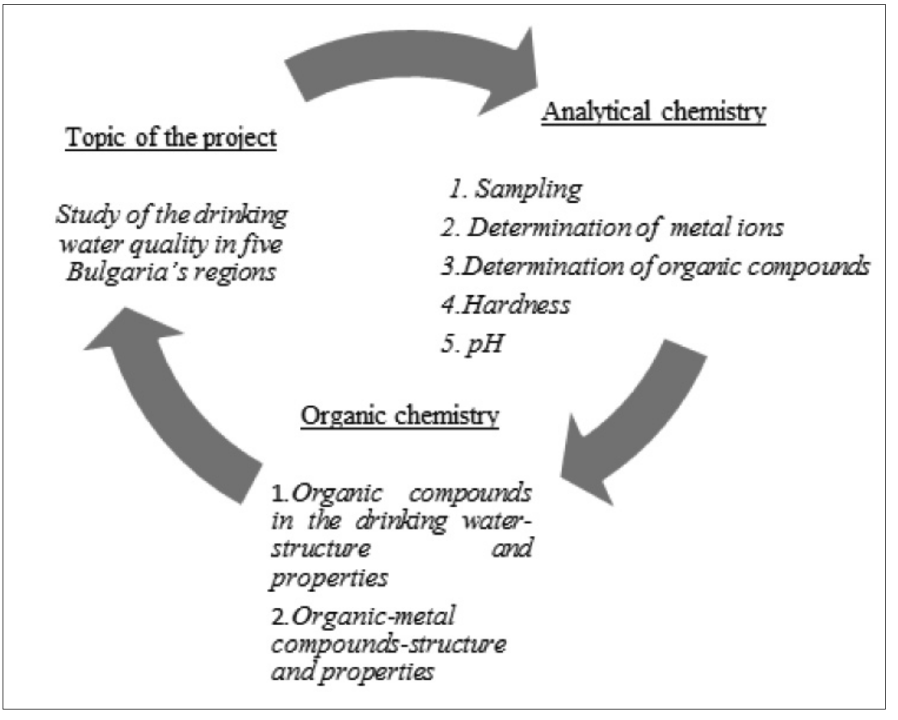


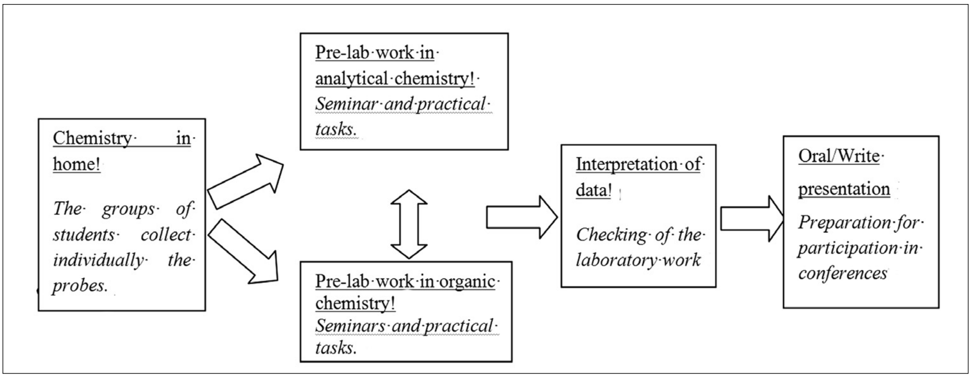
Figure 2. Correlation between different chemical disciplines in the "water quality project"

We can describe the steps for the project implementation by Fug. 3, as follow:

Table 1. Topic of the "water quality problem" split into the student groups

Number of the groups (G)	"Water quality problem" topic
G1	Determination of pH in drinking water
G2	Determination of hardness in drinking water
G3	Determination of sodium and calium ions in drinking water
G4	Determination of Cu, Cd and Pb in drinking water
G5	Determination of manganese and iron in drinking water
G6	Determination of organic compounds in drinking water

Figure 3. Steps for "water quality project" implementation



Design the experiments samples

In order to evaluate the degree of quality of drinking water quality used for drinking purposes, sampling was done from tap drinking water passing through the urban areas of Stara Zagora (P1), Gorna Oryahovitsa (P2), Parvomai (P3), Dupnica (P4) and Sofia (P5) (Fig. 1).

Total twelve water samples were collected from the five different locations. The sampling work was undertaken according to specified procedures.[2)] Sampling was done in the properly cleaned plastic jars. These plastic sampling jars were rinsed three times before the water samples were collected.

Pre-lab tasks at the beginning of the first semester

According to the lecture course and the "water quality problem" in the start of the project a small amount of pre-lab work was given to the students. The students were asked to answer a few simple questions for remembering, understanding and applying the information parallel in two disciplines and to search for some safety measures and given a bibliography to support the practical work by groups (Table 2-A and Table 2-B). Each group of students had to choose and answered of one of the questions to the end of the first semester.

Table 2-A. Examples for pre lab work tasks for laboratory and seminar work by analytical chemistry according to the "water quality problem

Tasks for laboratory and seminar work by analytical chemistry
Task for remembering and understanding the information 1.What means pH of a solution? 2. What means hardness of the water? Haw we can determinate the hardness of water? 3. Way is necessary to Na and K determination in drinking water? Could you determination Na and K ions by titrimetric methods? Show methods for Na and K determination in drinking water according to the literature.

4. Way is necessary to Cu, Cd and Pb determination in drinking water? Could you to Cu, Cd and Pb determinate by titrimetric methods?
5. Way is necessary to Fe and Mn determination in drinking water? Could you Fe and Mn determinate by titrimetric methods?
6. What means "chemical oxygen demand"? Way is necessary to determination the organic compounds in drinking water?

Tasks for applying the information in analytical chemistry

1. The label on the mineral water claims that it is pH =9. What do you think 'pH =9' means?
2. A glass of "ice tea" has [H3O+] = 4 x 10^{-4} M. What is the pH of the ice tea?
3. Atomic absorption method for calcium determination in water samples is used. 5.00 ml natural water were taken and diluted in a volumetric flask to 50.00 ml with distilled water. Then absorbance A = 0.475 is measured. The constant calibration is 1.102 $[cm.mg/l]^{-1}$.What is the concentration (μg / ml) of calcium in the water sample.
4. Determine the concentration of Cu ions in drinking water if the signal measured is E = -0.050 V. The coefficients of analytical function are calculated by regression analysis after calibration with external standard. There values are: slope: 30 V and intercept: -119.95 V. Which methods is used for the copper determination?

5. For determination of iron in water samples by atomic flame absorption method is obtained non-linear dependence: absorption-concentration. Explain the reasons for the observed effect and how to repair it?

6. The flame photometric detection is made for determination of K and N in drinking water. Volumes of 5.00; 1.00; 15.00; 20.00 and 25.00 ml standard solution containing 10.00 μg / ml K and Na, respectively were introduced in five volumetric flasks (50.00 ml). The values of sodium radiation intensity measuring at the wavelength λ = 589.0 nm are: 0.290; 0.570; 0.850; 1.40 and 1.390, and the radiation intensity of K at λ = 766.0 nm: 0.245; 0.490; 0.750; 1.010 and 1,250. Volume of 1.00 ml from analyzed sample is diluted in a volumetric flask (50.00 ml) and the value of emission intensity for potassium and sodium are: I_K = 0.620 and I_{Na} = 0.800. Define the content of K and Na in mg / l in the sample.
7. Write out the reduction reaction for dichromate in determination of total oxygen in the water samples. What is the molar ratio of the reaction between oxygen and dichromate?

Table 2-B. Examples for pre lab work tasks for laboratory and seminar work by organic chemistry according to the "water quality problem"

Tasks for laboratory and seminar work by organic chemistry
Task for remembering and understanding the information 1. Could you pH measure in solution of ethanol? What is the color of pH-indicator methyl orange in acidic solution? Give the explanation? 2. What are volatile organic compounds in drinking water? 3. Explain the solubility of organics compound in water as process. Which of the following compounds are more solubility in water: ethanol, phenol, acetone, benzoic acid? 4. Could you give the qualitative test of organic compounds: alcohols and phenols? Explain in oral presentation. 5. According to world healed organization the maximum acceptable concentration of alkylbenzenesulfonates in drinking water is 0.5 mg/l. Write an equation for the formation of alkylbenzenesulfonate and explain the process. 6. Which of the metals: Cu, Cd, Pb can react with organic compounds as phenols and alcohols containing in the water?
Tasks for applying the information 1. Draw the molecules of the complexes between ions Ca and Mg with the molecule of EDTA. 2. What is the difference between sodium and potassium soaps? Explain in oral presentation. 3. From where could occur detergents (organic compounds, soaps, shampoos, et al.) in drinking water? Explain in oral presentation. 4. How we make difference between primary, secondary and tertiary alcohols by Jones Reagent. Give the examples? Explain in oral presentation. 5. Show the chemical structure of least four pesticides? Draw the chemical structures of three pesticides that can meet in drinking water. 6. The most common organic compounds that are found in drinking water are fuel components as benzene, methyl tert-butyl ether, toluene and xylenes. Draw the chemical structures of three derivatives that are used in chemical technologies for drug preparation.

Pre-lab tasks at the beginning of the second semester

In the following step the amount of pre-lab work was increased, with the intention to help students to become more independent and to be fully conscious of the work they have to perform in the laboratory. Tasks in the second semester were mainly related to the methods used for analysis of the samples (Table 3). The aim of this pre lab tasks was the students to learn about principles of used analytical methods. The students prepared the most of the pre-lab tasks in oral presentation, which helped them for final project presentation.

Table 3. Pre lab work tasks in the second semester

Number of the groups (G)	Analytical chemistry	Organic chemistry
G1	Which method will use for pH determination? *Explain the principle of the method in oral presentation*	Could you pH determination in presents of organics ions in the water? *Explain in oral presentation.*
G2	Which method will you use for hardness determination? *Explain the principle of the method in oral presentation*	Could you determination of hardness in the water in the presents of organics ions? *Explain in oral presentation.*
G3	Which method will use for Na and K determination in drinking water? *Explain the principle of the atomic emission spectroscopy in oral presentation.*	Give the structure of soap and explane in oral presentation the mechanism of cleansing?
G4	Which method will use for Cu, Cd and Pb determination in drinking water? *Explain the principle of voltamperometry in oral presentation*	Give the methods for synthesis of complexes between Cu, Cd and Pb with ascorbic acid. *Explain in oral presentation.*
G5	Which method will use for Mn and Fe determination in drinking water? *Explain the principle of the atomic absorption spectroscopy in oral presentation*	Give the methods for synthesis of complexes between Mn and Fe with acetic acid. E*xplain in oral presentation.*
G6	Which method will use for determination of organic compounds in drinking water? *Explain the principle of the back titration of dichromate in oral presentation.*	Show the methods for purification of organic compounds in drinking water. *Explain in oral presentation.*

Students' data

The students were collected the water samples in the end of the second semester.

Immediately after collection, the samples were analyzed for pH, hardness, organic compounds, sodium, potassium and heavy metals by the standard methods (Table 4). Because the problems were fairly open-ended, the first challenge the students face was defining the problem. Before jumping into the laboratory, the analytical teams prepared proposals, completed with a detailed analysis, and described their approach for attacking the problem in an oral presentation answering the pre-lab questions from the two semesters. After that the students used voltammetric, atomic absorption/emission, and ion-selective electrode methods for analysis after properly calibrating the equipment with standards for precised results. All work groups finished the laboratory work presenting the data as graphics or tables and gave their conclusions (Table 4-A and Table 4-B). The data indicate that the tap water used for drinking purpose from all Bulgarian regions is no polluted and suitable for human consumption.

In the end of the "water quality project" were given detailed feedback in oral presentation on each "water problem". An overall list of tips was compiled for giving good student presentations: (i) well-structured with a clear introduction emphasizing the problem; (ii) extensive use of graphics, using time colors carefully; (iii) prepare and practice; (iv) speak slowly, clearly and loudly; (v) simple language and expression; (vi) good eye contact with audience.

In addition the results were also reported through a presentation to a public forum for "Tenth conference of students, young science and PhD students" at University of Chemical Technology and Metallurgy in May, 2014 (Fig. 4).

Conclusions

Thanks to the "water quality project" at the beginning of the year we found that the student's willingness to carry out a scientific work is increased. The students become more motivated and committed to the learning process. Over 80% of all project users passed the analytical and organic chemistry exams with better assessments at the end of the project. The results of the exams are given in Fig. 5. Moreover, many of the participants wanted to continue with scientific work as activity students in the both chemical disciplines.

Table 4-A. Students water quality data and conclusions

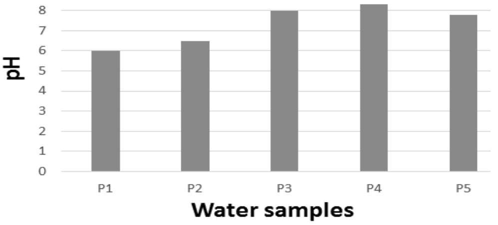
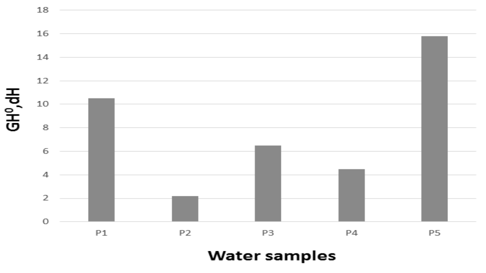
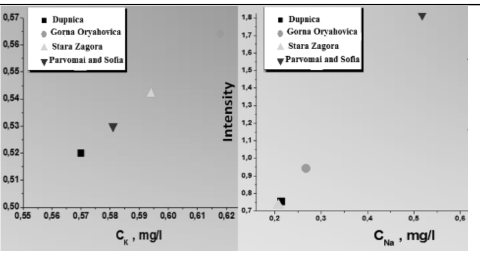
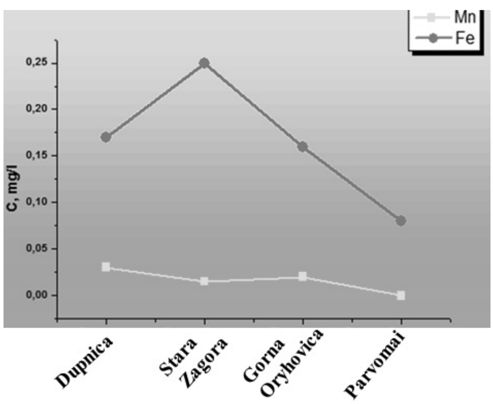
<table>
<tr><th>Water quality problem and used methods</th><th>Water data</th><th>Students conclusions</th></tr>
<tr><td>pH and hardness of the water
used method: potentiometry</td><td>
</td><td>pH determination: pH values of all collected samples are in the range according to recommended value of World Health Organization(WHO, 2007) that is, 6.50 to 8.50.</td></tr>
<tr><td>Hardness of the water
used method: titrimetry</td><td>
</td><td>Hardness: In groundwater, hardness is mainly due to carbonates, hydroxycarbonate, sulphates and chlorides of Ca and Mg. The maximum limit of total hardness recommended by WHO is 300 mg/L 18. Hardness values in all drinking water samples are in the range of 2 to 16 GH, dH (Table 1) which are in agreement with the results given by WHO.</td></tr>
<tr><td>Na and K determination
used method: atomic emission absorbtion</td><td>
</td><td>Sodium and potassium were found in the water samples in the range of 0.2 to 0.55 mg/L and 0.57 to 0.60 mg/L, respectively. Only one sample showed higher concentration for sodium than the other that is, 0.62 mg/L while in all other samples it is in normal level. Sodium in drinking water is not a health concern for most of the people, but may be an issue for someone with heart diseases, hypertension, kidney disease, and circulatory illness or on sodium controlled diet.</td></tr>
</table>

Table 4-B. Students water quality data and conclusions

<table>
<tr><th>Water quality problem and used methods</th><th>Water data</th><th>Students conclusions</th></tr>
<tr><td>Cu, Cd and Pb determination
used method: voltammetry</td><td>
<table>
<tr><th>Sample</th><th>C_{Cu}, ppm</th><th>C_{Cd}, ppm</th><th>C_{Pb}, ppm</th></tr>
<tr><td>P1</td><td>0.778</td><td>0.00173</td><td>0.00964</td></tr>
<tr><td>P2</td><td>1.079</td><td>0.00231</td><td>0.00793</td></tr>
<tr><td>P3</td><td>0.928</td><td>0.00147</td><td>0.00856</td></tr>
<tr><td>P4</td><td>0.257</td><td>0.00220</td><td>0.00635</td></tr>
<tr><td>P5</td><td>0.821</td><td>0.00154</td><td>0.00349</td></tr>
</table>
</td><td>The maximum permissible limit for copper, cadmium and lead recommended by WHO are 1.3, 0.005 and 0.015 ppm [18]. As one can see the values of this ions in all drinking water are in the rank of values defined by WHO.</td></tr>
<tr><td>Mn and Fe determination
used method: atomic flame absorption</td><td>


</td><td>The observed concentrations of Mn and Fe in samples show that the concentration varies from 0.01 to 0.03 mg/L for Mn and from 0.07 to 0.25 mg/L for Fe. The permissible limit of manganese and iron are 0.05 and 0.30 ppm in drinking water defined by WHO, 2007.</td></tr>
<tr><td>Organic compounds determination (Chemical oxygen demand)
used method: redox titrimetry</td><td>Dupnica - 5mg/L; Stara Zagora – 4,2 mg/L; Gorna Oryhovitca - 1.2mg/L; Parvomai - 2.2mg/L; Sofia - 2.01mg/L</td><td>The values of organics compound determination are normally associated with the drinking water samples according to WHO [18].</td></tr>
</table>

Figure 4. Poster presentation for "Tenth conference of students, young science and PhD students" at University of Chemical Technology and Metallurgy, May, 2014

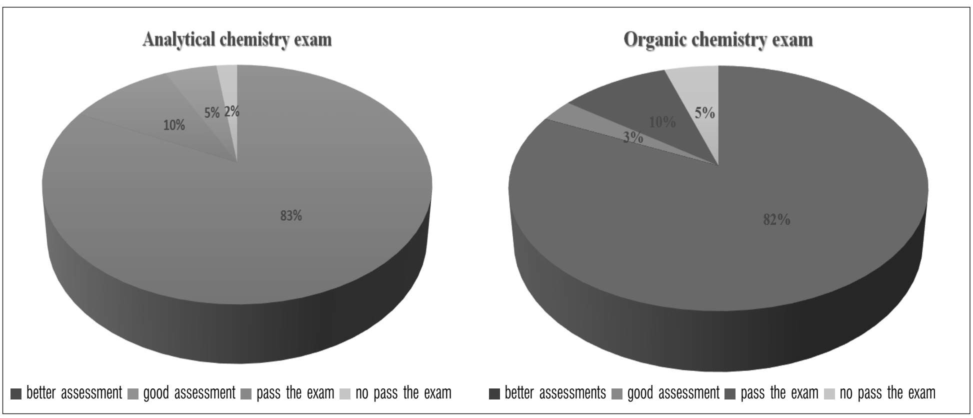


Figure 5. The project participants' results of examinations by analytical and organic chemistry

NOTES

1. http://apps.who.int/iris/bitstream/10665/44584/1/9789241548151_eng.pdf
2. http://www.mwa.co.th/download/file_upload/SMWW_1000-3000.pdf

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