PROJECT-ORIENTED TRAINING OF BACHELOR'S DEGREE STUDENTS IN CHEMISTRY

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ABSTRACT

Surgut State University joined the CDIO initiative in June 2017 at the 13th International Conference in the University of Calgary with three Bachelor's programs, including Chemistry. In accordance with standard 4, the discipline "Introduction to project activity" (1-2 semesters) has been introduced to the reformed curriculum. It forms the foundation for engineering practice and project activity in the field of creating products (chemical substances and materials) and systems (methods and technologies) and is aimed at learning basic personal and interpersonal competencies. In the first semester, students of a Chemistry program immerse themselves in the theory of project activities, and in the second semester they choose the project (for example, the creation of new materials covering silicon solar cells or the development of a chemical monitoring system for plants grown in closed systems) and assemble a team. In the second year, a team of students continues to work on the project at the discipline "Project Activity". The main goal of the second stage is the advanced hypotheses confirmation (the study of the physicochemical properties of substances and materials, technology optimization) and the testing of created products and systems in real conditions. During this stage, not only do students receive new knowledge about research methods but also they get experience in analytic equipment and processing of analysis results.
Thus, in accordance with the standard 5: a first and a second year student at the Chemistry program participates in at least in two educational and practical disciplines in designing and creating products, one of which performs in the first course at an elementary level, and the second one at an advanced level. Along with professional competencies, students develop their personal and interpersonal competencies (communication, flexibility, ability to work in a team), as well as increase the level of personal motivation for engineering professions in chemistry.

KEYWORDS

Syllabus, learning outcomes, project activity, standards: 1, 2, 3, 4, 5.

INTRODUCTION

Surgut State University joined the CDIO initiative in June 2017 at the 13th International Conference in the University of Calgary with three Bachelor's programs, including Chemistry (Petrova, 2018).

In accordance with standard 4, the discipline "Introduction to project activity" (1-2 semesters) has been introduced to the reformed curriculum. It forms the foundation for engineering practice and project activity in the field of creating products (chemical substances and materials) and systems (methods and technologies) and is aimed at learning basic personal and interpersonal competencies. In the 1st semester, students of a Chemistry program immerse themselves in the theory of project activities, and in the 2nd semester they choose the project (for example, the creation of new materials covering silicon solar cells or the development of a chemical monitoring system for plants grown in closed systems) and assemble a team. The project leader of a student team is a professor who helps students to define the project's goals and objectives, as well as a project plan. The leader appoints a project curator (5th course or PhD student) who helps 1st year students to distribute tasks among team members and oversees the implementation of project stages. In addition, the leader and the curator have got professional competencies that allow students to be trained on how to create products and systems. For example, students obtain nanocomposite materials with semiconductor properties using molecular imprinting technology of perylenediimide dyes on the surface of titanium dioxide nanoparticles; or create a system of plant state chemical monitoring in the interdisciplinary project "The Local Farm", launched by the Institute of Natural and Technical Sciences of the Surgut University. Let us focus on the latter project.

"THE LOCAL FARM" PROJECT

Local (vertical) farms are multi-tiered or tubular hydroponic installations, in which, as a rule, a whole range of greens and lettuce cultures are grown using solar or artificial lighting with a lamp system. Such farms with productivity more than 100 times higher than the productivity of traditional greenhouses have appeared in the USA, Japan, Singapore and European countries. They are capable of producing hundreds of tons of products annually, ensuring the food security of the population of cities and regions.

The goal of the Surgut University project is to develop an automated technology for growing crops in greenhouses according to the principles of agrophotonics in local (vertical) farms and to create an intelligent system for the management of the local farm resources. The technology provides the production of finished products from previously germinated seeds, thus it can be implemented in any climatic conditions in the presence of seed material, as well as in remote and inaccessible regions of the North and the Arctic, providing indigenous people and shift workers with fresh products rich in nutrients and vitamins (Fig. 1).

Compared to world analogues, this project will create an automated system for controlling hydroponic installations of local farms using controllers, video surveillance cameras, sensors and chemical monitoring system. The controllers directly control basic parameters of a farm, such as temperature, humidity, lighting, watering, fertilizers, etc. Obtaining information about the current value of the parameters is carried out by using sensors: temperature, humidity, light, etc. Control actions are calculated by a controller based on the current values of parameters and necessary values received from the server. The additional control over the plant growing process is carried out by using surveillance cameras installed on the farm, the image from which is processed and stored in real time on a cloud server, where a cloud database is formed, and then transferred to a remote client. In addition, the quality and plant state control of each grown batch is carried out by using methods of chemical analysis. The complex of chemical analysis techniques, determined indicators and the quality and the plant state data form a chemical monitoring system, which is also stored in a cloud database. The cloud-server serves as a repository for the history of monitoring farm parameters, as well as a communication channel between the remote client and the controller. A remote client is a web application that is used to initialize the farm, as well as to monitor and control the process of growing plants. All parts of the system are connected via the Internet.

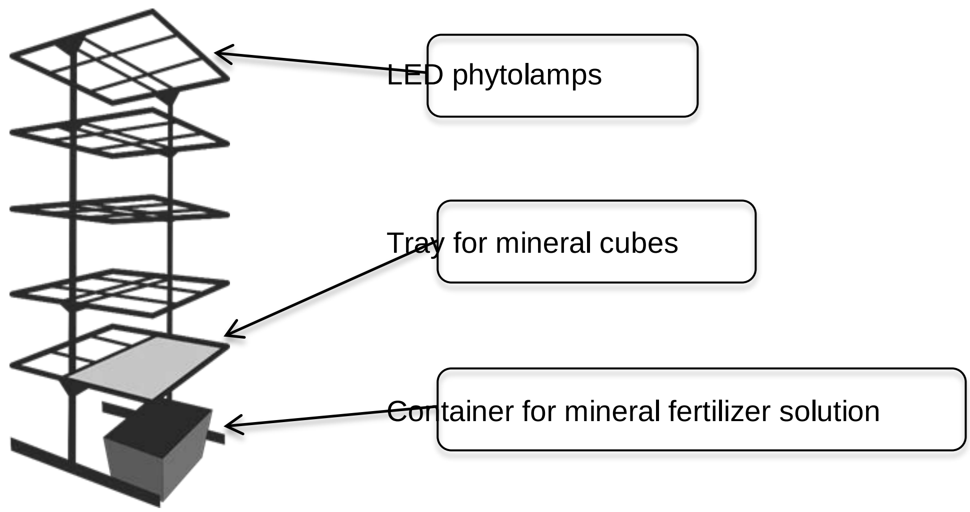

Figure 1. Structure description and its main elements of the local farm

The “Local Farm” project at the Surgut University was launched in October 2018. The first test batch of plants (14 species of lettuce and essential oil plants) was obtained in December 2018. Cut samples were transferred to a laboratory for chemical analysis. The samples were stored in a refrigerator for 2 days. For the formation of a chemical monitoring system, a team consisting of 5 undergraduate 1-st year students of Chemistry, 2 postgraduates, 2 technicians and a lecturer of chemistry department was formed.

At first, the professor (leader) gave students the task to study the literature on chemical analysis of plants, and technicians and graduates (curators) - to evaluate the material and technical resources of the Chemistry Department to carry out the experimental work. To start the monitoring system, three methods were chosen for a dry matter determination by a gravimetric method, nitrates by ionometry and elemental composition by an X-ray fluorescence analysis. Standard methods were used: GOST 26671-2014 "Products of processing of fruits and vegetables, canned meat and meat and vegetable preserves. Sample preparation for laboratory tests", GOST 29270-95 "Products of processing of fruits and vegetables. Methods of nitrate determination” and GOST 28561-90 “Products of processing of fruits and vegetables. Methods of dry matter or moisture determination”. The students carried out experimental studies by a team under the guidance and supervision of curators who also taught them how to work with the used equipment: drying ovens, muffle furnace, ionomers with nitrate-selective electrodes, energy dispersive X-ray fluorescence analyzer. The obtained results for normalized indicators (nitrates and heavy metals) were compared with the permissible levels of nitrates for fresh lettuce grown in greenhouses from October 1 to March 31 (SanPiN 2.3.2.1078-01 "Hygienic requirements for safety and nutritional value of food products", section 1.6. Fruits and vegetables) - 4500 mg/kg, and maximum permissible concentrations (MPC) of heavy metals in plants (Baker, 1981).

Determination of dry matter was carried out in three samples of lettuce cultures by the thermogravimetric method. Samples were ground by grinding in a mortar. Nitrates were extracted with a potassium aluminum sulfate alum solution. The subsequent determination of nitrate concentration was performed using an ion-selective nitrate electrode by the calibration curve method (Table 1). Exceeding the permissible nitrate content in the studied varieties of lettuce can be caused both by the individual characteristics of plants (the ability of plants to accumulate nitrates largely depends on their type and variety), and by low light and humidity in the laboratory. With a decrease in light and humidity, the nitrate concentration in different cultures may increase by 2-10 times (Andryushchenko, 1983).

Table 1. Results of determination of dry matter and nitrates in lettuce cultures samples

№	Sample	Dry substances,%	Nitrates, mg / kg
1	L3	4,5	5204
2	L5	3,4	6371
3	L6	4,2	5643

Elemental analysis was carried out after dry ashing of 14 samples of cultures in a muffle furnace at 500°C for 4 h. The ash was pressed into tablets weighing 2,5-2,7 g (20 mm diameter) with boric acid as a carrier using a laboratory hydraulic press. X-ray fluorescence intensity measurements were made under vacuum on energy-dispersive X-ray fluorescence spectrometer EDX-8000 (Shimadzu). Content of elements in the samples was calculated using PCEDX-Pro software and fundamental parameters method (Table 2).

Table 2. The results of elemental analysis of lettuce crops (L) and aromatic plants samples: basil (B), parsley (P), dill (D), arugula (A)

Element	Samples										MPC, mg/kg
	L1	L3	L4	L5	L6	E8	B11	P12	A13	D14	
	Content, %										
K	81,11	79,58	74,46	77,10	75,34	76,90	73,38	81,11	56,80	80,21	-
Ca	8,71	10,53	14,15	10,80	13,51	11,68	16,01	7,82	20,90	10,50	-
P	5,13	4,50	5,16	5,89	4,99	5,83	5,78	5,91	4,47	4,95	-
Mg	1,82	2,08	2,24	2,68	2,46	1,47	1,94	1,97	3,96	1,35	-
S	1,74	1,84	2,08	2,01	2,44	2,42	1,71	1,73	12,80	1,63	-
Cl	0,58	0,61	0,97	0,69	0,42	0,64	0,45	0,94	0,41	0,62	-
Sr	0,13	0,16	0,20	0,15	0,19	0,17	0,24	0,10	0,32	0,14	-
Si	0,37	0,24	0,30	0,26	0,25	0,55	0,22	0,08	-	0,19	-
Mn	0,16	0,15	0,18	0,21	0,16	0,13	0,09	0,07	0,18	0,20	0,3
Fe	0,14	0,19	0,15	0,11	0,13	0,12	0,07	0,17	0,08	0,10	-
Zn	0,04	0,07	0,04	0,04	0,05	0,03	0,05	0,03	0,03	0,04	-
Cu	0,03	0,03	0,03	0,03	0,03	0,03	0,04	0,03	0,03	0,03	5,0
Rb	0,03	0,03	0,03	0,03	0,03	0,02	0,02	0,03	0,02	0,02	-
Br	0,008	0,004	0,007	0,003	0,005	0,004	0,005	0,005	0,003	0,006	-
Ag	0,007	-	-	-	-	-	-	-	-	-	-

Plants are an intermediate link through which elements pass from soil, air, water to animal and human organisms. Both macro- and microelements were found in the studied plant samples (Table 2). The normalized superecotoxicants include heavy metals, which are distinguished by hazard class (Baker, 1981): lead – 1 class; chromium, molybdenum, copper – 2 class;

manganese – 3 class. Only manganese and copper were found in the studied samples. Therefore, plants in greenhouses do not accumulate many heavy metals and are safer compared to those grown in the open (unprotected) soil that is subject to man-made pollution.

PROJECT ACTIVITY

The tasks assigned to students in the project by the teacher and curators can be divided into five groups: a review on chemical analysis of plants, sample preparation (grinding, extraction, ashing, etc.), measurements, processing results and report, presentation and project defense at Chemistry department (Table 3). Students distributed the work in the project on their own, adhering to the principles of ethics, honesty, justice, trust and loyalty. Each experimental task in three determinations (dry matter, nitrates and elemental composition) was performed by 1-2 students. In addition, students who did a review on selected methods were engaged in processing the results, preparing a report and part of the presentation. Consequently, each of the five students in their work performed all kinds of project tasks.

Table 3. Task distribution in the project

Student	Tasks				
	Review	Sample preparation	Measurements	Processing results and report	Presentation
1. Determination of dry matter					
Student 1	+			+	+
Student 2		+			
Student 3		+			
Student 4			+		
Student 5			+		
2. Determination of nitrates					
Student 1			+		
Student 2	+		+	+	+
Student 3	+			+	+
Student 4		+			
Student 5		+			
3. Elemental analysis					
Student 1		+			
Student 2		+			
Student 3			+		
Student 4	+		+	+	+
Student 5	+			+	+

At the end of the second year, students defend the project at the Chemistry Department. The project results can be presented by one or several team members, all students of the group take part in the discussion, and the committee of professors of the department evaluates the students. According to the defense results and the submitted report, students receive a credit for the subject “Introduction to project activities”.

The result of the project activities of first-year Chemistry Program students, integrated into the interdisciplinary project of Surgut State University “The Local Farm”, was the creation of chemical monitoring system of the state and quality of plants grown in protected (closed) soil.

Such monitoring system allows to optimize the technology of growing various crops in the laboratory (at the stages of project implementation), and can also be transformed into the conditions of crop production.

All students in the Local Farm project had got credit for “Introduction to project activities” subject. The student feedbacks were positive. They enjoyed working in a team and participating in a real interdisciplinary project. In addition to professional skills in chemical analysis, they received skills in teamwork and interpersonal communication, as well as presenting the results of the project.

In the second year a team of students continues to work in the project at the discipline "Project Activity". The main task of the second stage is to confirm advanced hypotheses (the study of the physicochemical properties of substances and materials, optimization of technologies) and the testing of created products and systems in real conditions. At this stage, students not only get new knowledge about research methods, but also they get experience in analytic equipment and processing of analysis results. In addition, the approbation of products and systems can take place in the enterprises of industrial partners of the university. Therefore, the project products and systems can be estimated by the industrial partners. So, in the “The Local Farm” project in the second year, students continue to expand the created chemical monitoring system with new methods of chemical analysis of plants, test it in real conditions with new objects, optimize the technology of growing crop products, form a cloud monitoring data system.

In accordance with the list of planned learning outcomes of graduates (CDIO Syllabus) in engineering and technology educational programs (Crawley, 2013), we conducted a comparative analysis and coordination of the requirements contained therein with the competencies of bachelors on Chemistry, set out in the new standards of FGOS 3^{++} (Russia) and implemented in the disciplines "Introduction to project activities" and "Project activities" (Fig. 2). It was shown that the requirements for learning outcomes are in good agreement with the competences in the categories of general professional skills (OPK-1 and OPK-2), intercultural interaction (UK-5), teamwork and leadership (UK-3), communication (UK-4), project development and implementation (UK-2). This demonstrates the applicability of CDIO standards to the implementation of Bachelor’s programs on Chemistry.

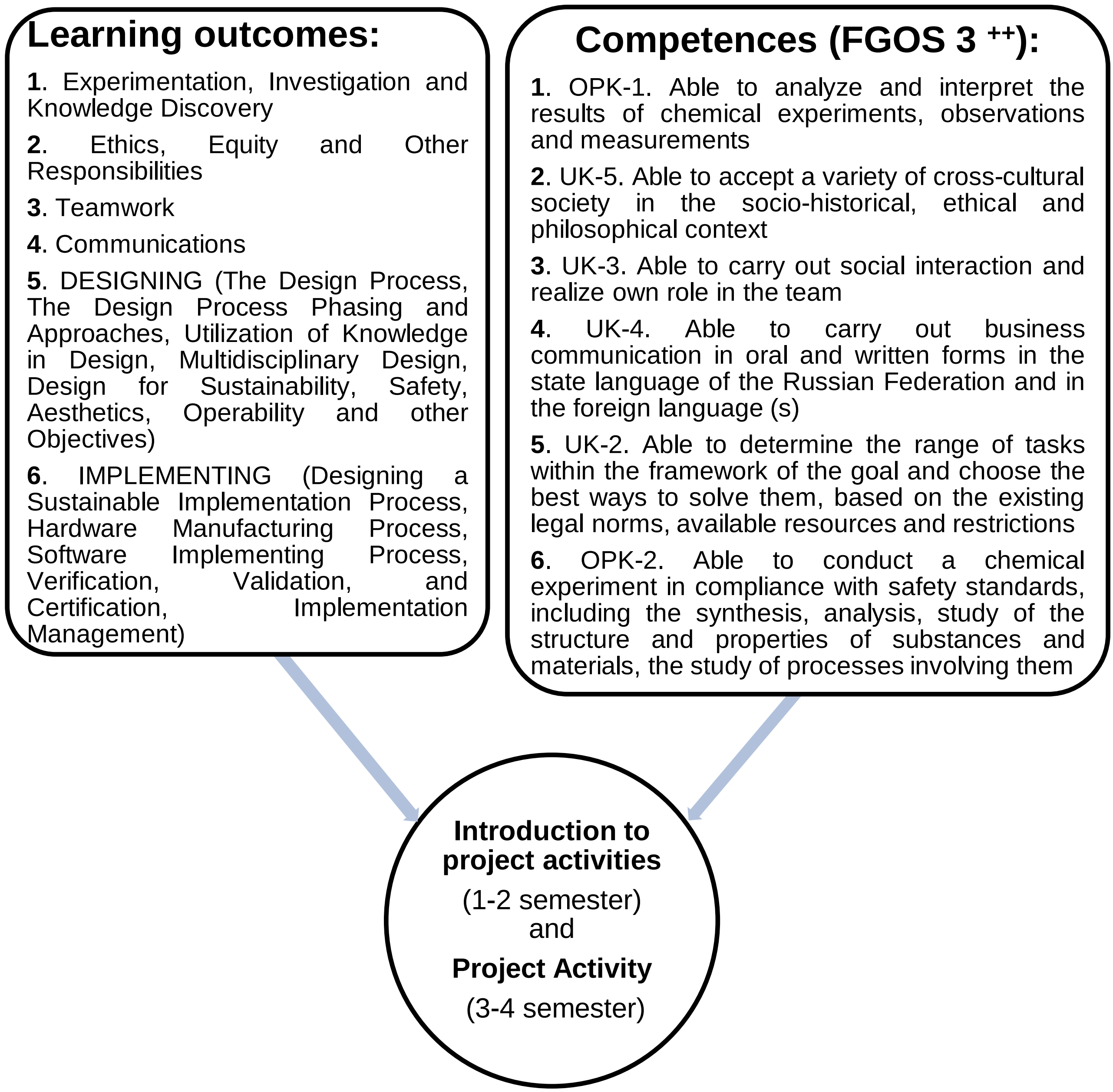

Figure 2. Comparative analysis of learning outcomes (CDIO Syllabus) and competencies (FGOS 3^{++}) implemented in the disciplines "Introduction to project activities" and "Project activity" of Bachelor's Program on Chemistry

CONCLUSION

Thus, in accordance with the standard 5: a 1-st and a 2-nd year student of the Chemistry program participates in at least two educational and practical disciplines in designing and creating products, one of which performs in the first course at an elementary level, and the second one at an advanced level. Along with professional competencies, students develop their personal and interpersonal competencies (communication, flexibility, ability to work in a team), as well as increase the level of personal motivation for engineering professions in chemistry.

During the project activity, not only do students receive new knowledge about research methods but also they get experience in analytic equipment and processing results of analysis. In addition, the approbation of products and systems can take place in the enterprises of industrial partners of the university. Therefore, the project products and systems can be estimated by industrial partners.

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