EXPERIENCE IN THE DEVELOPMENT OF BACHELOR'S PROGRAM "CHEMISTRY"

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ABSTRACT

The challenges of regional economy and industry high demand in the engineering personnel caused the need of Bachelor's Chemistry program reforming in accordance with the best international practices. The study of industry needs for the formation of learning outcomes was carried out by questioning of the graduates and the largest companies that employed them. The questionnaire for employers consisted of general cultural and professional learning outcomes with the expected and real level. The research results have showed that personal qualities and teamwork skills take the first place among employers. Nevertheless, communication skills, design, planning and organization of the industrial enterprise, as well asexternal and social context have received the lowest assessment level of graduates and employers.

The curriculum development process is related to the first 5 CDIO standards. In order to meet Standard 1, it was stated that the Chemistry program curriculum is based on the CDIO framework as a context for industrial engineering education. To implement the Standard 2 and 3, graduate attributes were determined for the purpose of practice-oriented learning. Graduate attributes correspond with the set of knowledge and skills of CDIO Syllabus and learning outcomes. The next important stage of the work was the curriculum reforming in accordance with the graduate attributes and the learning outcomes (Standards 4-5). Thus relevant competencies of the Chemistry educational standard were compared to the attributes and the analysis of the disciplines that form these competences was carried out. As a result of the work, 25 new disciplines were introduced corresponding to the most demanded learning outcomes, 40% of curriculum was reformed, the modular approach and the practical-oriented activity were integrated.

KEYWORDS

Graduates, Syllabus and learning outcomes, curriculum reforming, standards: 1, 2, 3, 4, 5.

INTRODUCTION

Modern engineers are engaged in all phases of the products lifecycle, processes and systems which serve needs of society. That is why it is the responsibility of engineering education to support their preparation for this. In Russia existing Bachelor's programs linked to Chemistry and Chemical Engineering content are often much focused on fundamental knowledge itself, so that students graduate as professionals who know how to solve pre-defined technical problems. Students of such programs seldom practice entrepreneurial, communication and innovation skills at the level that is expected and needed in working life.
The CDIO Initiative focuses on modernizing engineering education by introducing such skills and thinking into technical programs and courses. By implementing CDIO, students will be able to encounter more real-life problems, which are cross-disciplinary and are set in the context that may include social, legal, environmental and business aspects. Such problems are often characterized as complex and ill-defined, and there can be one or many solutions to be of importance in the light of specific conditions. Members of the CDIO Initiative have the opportunity to continuously develop as CDIO collaborators and regularly develop materials and approaches to share with others (Crawley et al., 2014).

SURGUT STATE UNIVERSITY

Surgut University is the leading university in Khanty-Mansiysk Autonomous Okrug (Russia). Surgut University joined the CDIO initiative in June 2017 at 13th International CDIO Conference in Calgary with three education programs, including the reformed bachelor's program Chemistry.
Khanty-Mansiysk Autonomous Okrug - Ugra is one of the strategic regions of Russia, providing energy security of the country and being the largest oil producing region of the state and the world. The strategy of socio-economic development of the region outlines the following: "The peculiarity of the innovative scenario is that the renewal of the structure and content of education should be planned for the future development of the labor market in accordance with international standards. The innovative scenario implies the need to ensure high rates of development of educational programs aimed at staffing the industries that generate innovation and, in general, the service sector".
Surgut State University, founded in May 1993, is the largest university in Ugra, which trains students in a number of fields of science and technology. It offers a wide range of bachelor's and master's programs, including ones in chemistry and analytical chemistry. The main goal of the university development is to transform into the university of a new type, supporting and providing innovative economic development of the region.
Alumni of the Surgut State University chemistry program work as engineers at the largest oil and gas companies and power stations in the field of quality control of oil and gas products, control of processes in oil recovery (EOR and IOR) and oil and gas processing technology. More than 40% of graduates work at JSC "Surgutneftegas", 24% - at JSC "Gazprom", about 20% - at the electric power industry. Graduates are employed in regional industry mainly as laboratory assistants in chemical analysis; laboratory assistants for sampling; laboratory assistants for quality control; laboratory engineers; chemical engineers and environmental engineers. Therefore, the reforming of educational programs in the field of chemistry based on practice-oriented principles has become an urgent task of modern chemical education.

What were the reasons for becoming a CDIO member?

- Improving quality of engineering education programs to meet the demand for high-skilled employees.
- Students' soft skills development.
- Reviewing engineering educational programs and establishing learning outcomes in close contact with stakeholders.
- Readiness of students to complete full lifecycle projects in a team.
- Integration of the university into the world scientific and educational environment via information and ideas exchange with other CDIO members.
- Enhance competitiveness of the university and its graduates on the national and global scale.

CURRICULUM OF THE BACHELOR'S DEGREE PROGRAM ON CHEMISTRY

The analysis of Chemistry program has showed that its strengths are the interdisciplinarity of project-oriented learning and the project activity of chemistry students and the improved pedagogical competences of the teaching staff, trained in distance education technologies at Moscow State University and in design of educational programs in accordance with CDIO principles at Tomsk Polytechnic University. Weaknesses of the program are associated with the lack of soft skills (interpersonal competencies) and methods for evaluating programs, the need to modernize the working space for student design activities and to improve the methods for evaluating teaching, as well as partial application of active teaching methods.
The study of the needs of industry for the formation of learning outcomes was carried out by questioning the largest companies that hire graduate chemists and graduates themselves. So the questionnaire for employers consisted of general cultural and professional formed learning outcomes with the expected and real level on a 5-point scale (Table 1).

The table (Table 2) shows the expected level of professionalism in the opinion of the industry and graduates. The research results have showed that personal qualities (1, 2, 4, 7-11) and teamwork skills (3, 14) take the first places among employers. However, communication skills (5), entrepreneurial and business context (14), as well as external and social context (6) have received the lowest assessment level of the graduates' and employers' expected professionalism.

Table 1. Questionnaire for employers for the definition of the learning outcomes formation level

№	Learning outcomes	Level of formation											
		Real						Expected					
1	Manage your time, build and implement the trajectory of self-development based on the principles of life learning	0	1	2	3	4	5	0	1	2	3	4	5
2	Demonstrate knowledge of social, ethical, cultural and economic aspects of professional activity	0	1	2	3	4	5	0	1	2	3	4	5
3	Effectively work independently and in team, including interdisciplinary and multicultural environment	0	1	2	3	4	5	0	1	2	3	4	5
4	Competently execute and report the results of work in written and oral form using the appropriate technical terminology	0	1	2	3	4	5	0	1	2	3	4	5
5	Active proficiency in the main European languages at the level that allows to study information and present results of professional activity	0	1	2	3	4	5	0	1	2	3	4	5
6	Use methods and means of health promotion, demonstrate commitment to a healthy lifestyle	0	1	2	3	4	5	0	1	2	3	4	5
7	Apply the knowledge of theoretical foundations of natural science disciplines, including the fundamental sections of chemistry in professional activity	0	1	2	3	4	5	0	1	2	3	4	5
8	Demonstrate a systemic interdisciplinary understanding of engineering sciences as applied to solve production problems	0	1	2	3	4	5	0	1	2	3	4	5
9	Plan and conduct laboratory tests using modern instrumentation, observe health and safety standards in chemical production, meet environmental protection requirements	0	1	2	3	4	5	0	1	2	3	4	5
10	Select and use, on the basis of fundamental and specialized knowledge, necessary reagents, equipment and techniques for conducting complex practical engineering activities, taking into account economic, environmental, social and other requirements	0	1	2	3	4	5	0	1	2	3	4	5
11	Interpret the data obtained as a result of theoretical and experimental studies in terms of their significance	0	1	2	3	4	5	0	1	2	3	4	5
12	To carry out, correct and develop the technological processes of chemical production	0	1	2	3	4	5	0	1	2	3	4	5
13	To plan and organize the work of industrial divisions	0	1	2	3	4	5	0	1	2	3	4	5
14	Demonstrate leadership in engineering activity and engineering entrepreneurship, responsibility for subordinates and the result of production activities; willingness to follow the corporate culture of the organization	0	1	2	3	4	5	0	1	2	3	4	5

Table 2. The level of learning outcomes formation

№ of learning outcomes	The levels of learning outcomes formation			
	Employers		Graduates	
	Real	Expected	Real	Expected
1	4,0 ± 0,5	4,5 ± 0,6	2,7 ± 1,0	3,5 ± 1,1
2	4,0 ± 0,6	4,0 ± 0,5	2,2 ± 1,1	2,5 ± 1,3
3	5,0 ± 0,9	4,0 ± 0,5	2,8 ± 1,1	2,2 ± 1,2
4	4,5 ± 0,5	4,0 ± 0,6	3,2 ± 0,9	3,3 ± 1,1
5	2,0 + 0,5	3,5 ± 1,3	1,5 ± 0,8	2,5 ± 1,5
6	2,0 ± 1,1	3,5 ± 0,9	2,0 ± 1,1	2,5 ± 1,6
7	5,0 ± 1,1	3,5 ± 0,8	3,2 ± 0,9	3,3 ± 1,1
8	5,0 ± 1,1	4,0 ± 0,5	2,7 ± 1,0	3,3 ± 1,1
9	5,0 ± 0,9	3,5 ± 0,8	3,3 ± 0,8	3,7 ± 1,0
10	5,0 ± 1,1	4,0 ± 0,5	3,5 ± 1,0	3,7 ± 0,8
11	5,0 ± 1,5	4,0 ± 0,0	3,3 ± 1,1	3,7 ± 1,0
12	2,0 ± 0,0	4,0 ± 1,0	2,2 ± 0,8	3,0 ± 1,3
13	3,5 ± 1,7	4,0 ± 0,8	2,0 ± 1,0	2,7 ± 1,6
14	4,0 ± 1,6	4,0 ± 0,0	2,3 ± 1,1	3,0 ± 1,3

DEVELOPMENT OF CURRICULUM OF BACHELOR'S PROGRAM ON CHEMISTRY

The CDIO Initiative started in the year 2000 with the aim to reform engineering education for a better professional preparation. The vision of CDIO is to educate students to master a deeper working understanding of technical fundamentals, the ability to lead in the creation & operation of products and systems, and an understanding of the role and strategic value of research (Berggren *et al*., 2003; Crawley *et al*., 2014).

The 12 CDIO standards disclose the philosophy of the program (Standard 1), the development of curricula (Standards 2, 3 and 4), the implementation of project activities and requirements for working space (Standards 5 and 6), teaching and learning methods (Standards 7 and 8), teacher training (Standards 9 and 10), as well as the assessment of learning outcomes and the overall program (Standards 11 and 12).

It is worth noting that the CDIO Syllabus is not a defining feature of CDIO. Each institution must formulate programme goals considering, e.g. stakeholder needs, national and institutional context, level and scope of programmes, and subject area. To accommodate diversity, the CDIO syllabus is offered as an instrument for specifying local programme goals by selecting topics and making appropriate additions in dialogue with stakeholders. As such, it has served as a reference for a multitude of engineering programmes and for diverse contexts and purposes (Edström *et al*. 2014).

The curriculum development process is related to the first 5 CDIO standards.

In order to meet Standard 1, it was stated that the curriculum of the Bachelor's program Chemistry is based on the CDIO framework as a context for industrial engineering education. In 2017 Surgut University joined the CDIO Initiative and the first set of students for the Chemistry program was implemented.

For the implementation of Standard 2 in the University attributes of the graduates (Table 3) "for the purpose of practice-oriented training of graduates" - who are ready for real-life work, were determined. Attributes of graduates correspond with the set of knowledge and skills of CDIO Syllabus and learning outcomes.

Table 3. Attributes of the Bachelor's program Chemistry graduates

№	Attribute	Description
1	Graduates with practice-oriented training	Ability to think, produce, design, solve problems, collaborate and meet requirements of industry
2	Knowledge	Knowledge of basic sciences, application of in-depth knowledge, integration of learning experience
3	Professional skills	Basic and advanced practical skills, meeting the requirements of industry in accordance with the Bachelor of Chemistry qualification
4	Personal and interpersonal skills	Knowledge of foreign language;
		Communication and Information Technology;
		Teamwork;
		Learning to learn;
		Analytical thinking and problem solving skills;
		Manner and behavior in the industrial sphere;
		Commitment to discipline and organization;
		Social activity and interest

Standard 3: It can be seen from the survey that top of 5 expectations from industry representatives are related to teamwork skills, personal qualities, key knowledge of the engineering basics, production and communication skills. The head of the educational program and the staff of Chemistry Department have worked to identify inconsistencies and eliminate shortcomings.

The next most important stage of the work was the reforming of the educational program in accordance with certain attributes of the graduate and the learning outcomes. To do this, we have compared relevant competencies of the educational standard 04.03.01 Chemistry (Russia) with the attributes of a graduate and the analysis of the disciplines that form these competences have been carried. As a result of this work, new disciplines were introduced (Figure 1), corresponding to the most demanded learning outcomes of program stakeholders. 40% of the educational program have been reformed as a result of this work (Figure 2): 25 new disciplines have been introduced, a modular approach has been integrated (in mathematics and physics courses), practice-oriented activities (coursework and projects, project activity, research activity) and interdisciplinarity.

Future Work

Further implementation of CDIO standards in the Bachelor's program on Chemistry in the current 2018 provides:

- Development of the content of the program disciplines in accordance with certain learning outcomes;
- Expanding the use of active teaching methods in the educational process;
- Modernization of the working space (educational environment) for the implementation of project-oriented learning;
- Development of distance courses of the program disciplines.

Prospects for CDIO engineering education development at the Institute of Natural and Technical Sciences are reflected in the development program until 2020 and envisage the reforming of the educational programs "Technospheric Security" and "Ecology and Nature Management" in the context of the engineering education of the International CDIO Initiative.

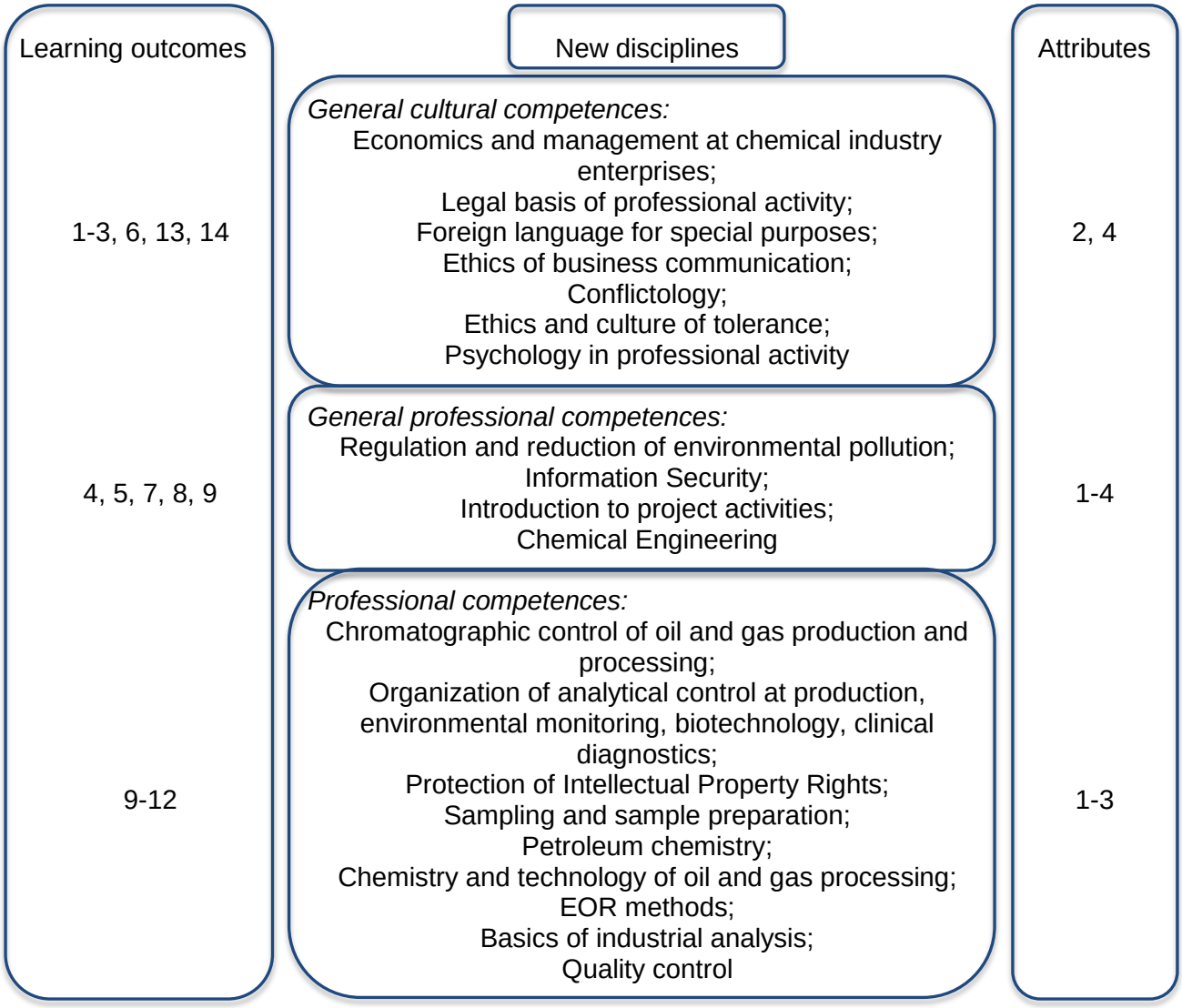

Figure 1. New disciplines of the curriculum Chemistry

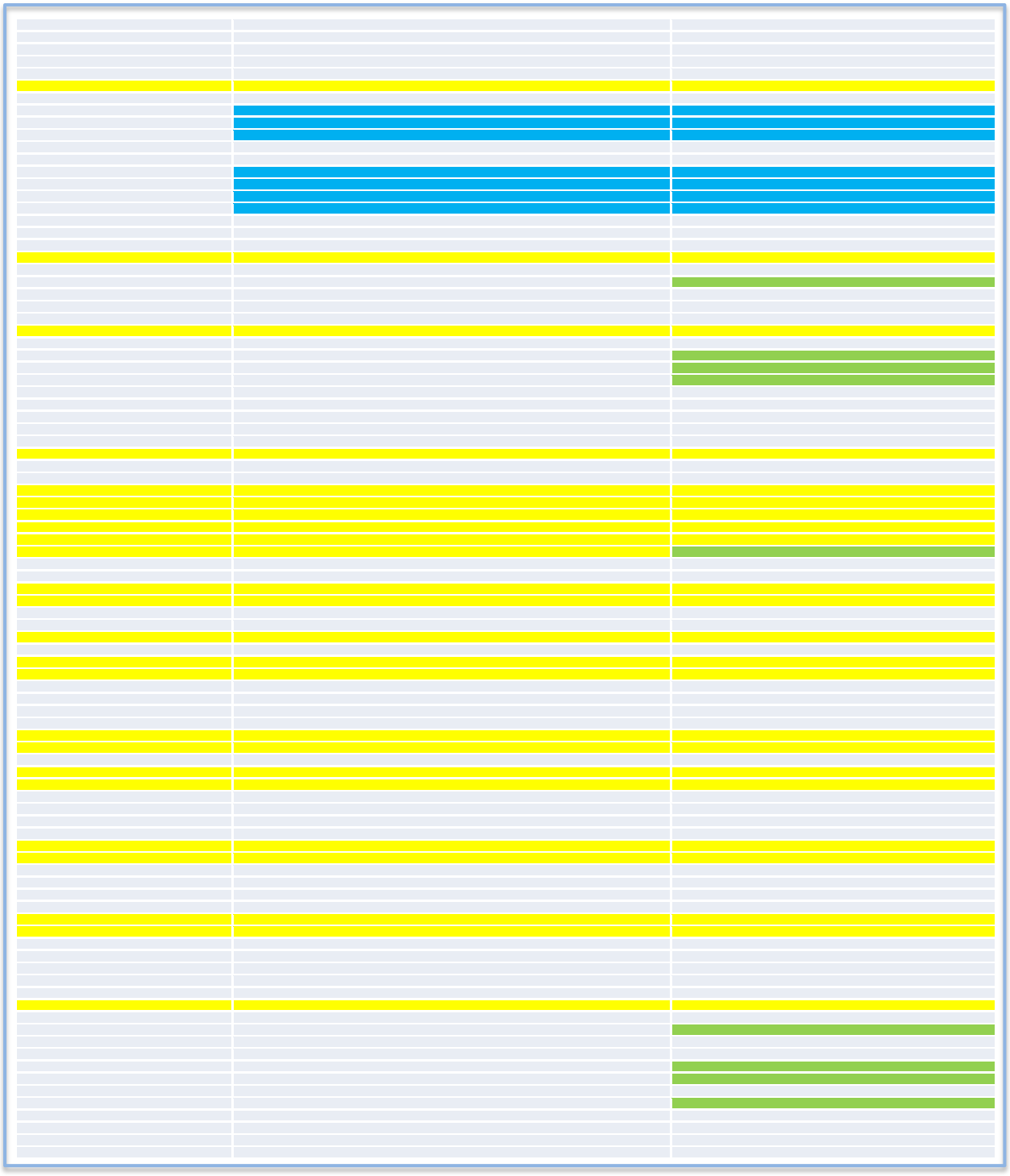

Figure 2. Color diagram of the curriculum Chemistry (yellow: new disciplines, blue: modules on mathematics and physics, green: coursework and projects, project activity, practices, research activity)

CONCLUSION

The CDIO team includes the leadership of the university represented by rector and pro-rector for development, director of Institute of Natural and Technical Sciences, teachers of chemistry department, representatives of the region's employers, including university graduates, and chemistry students themselves. Since 2016 a lot of work has been done: the Bachelor's program on Chemistry in the context of industrial engineering education has been revised and the curriculum has been reformed (standards 1-5).
In 2017 at the 13th International CDIO Conference (Calgary, Canada, June 18-22, 2017) Surgut University joined the International CDIO Initiative and in September of 2017 the first group of students began studying the reformed program.
In order to drive a continuous development and creation of sustainable education in Chemistry with true industrial involvement, a longer commitment of CDIO Initiative support is needed. This will further require wider faculty training with CDIO pedagogics, innovative laboratory development, and industry driven project course development within Chemistry.

REFERENCES

Berggren, K., Brodeur, D., Crawley, E., Ingemarsson, I., Litant, W., Malmqvist, J., & Östlund, S. (2003). CDIO: An international initiative for reforming engineering education. *World Transactions on Engineering and Technology Education, 2*(1), 49-52.

Crawley E. F., Malmqvist J., Östlund S., Brodeur D. R., & Edström K. (2014). *Rethinking Engineering Education: The CDIO Approach* (2nd ed.) New York: Springer.

Edström, K., & Kolmos, A. (2014). PBL and CDIO: complementary models for engineering education development. *European Journal of Engineering Education, 39*(5), 539-555.

BIOGRAPHICAL INFORMATION

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