TPU-SKOLKOVO PROJECT: MODERNIZATION OF BEng PROGRAMS IN RUSSIA

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ABSTRACT

In 2011 National Research Tomsk Polytechnic University (TPU) joined the CDIO Initiative. To work out the new national model for BEng programs TPU and SKOLKOVO Foundation initiated two-year project “Modernization of Bachelor’s Programs in Engineering in Accordance with International Standards of Engineering Education”. Seven leading Russian universities in Moscow (MEPhI, MISIS, MIPT, HSE), Saint-Petersburg (ITMO), Samara (SSAU) and Tomsk (TPU - coordinator) participate in the project. The main idea of the project is analysis of international standards of engineering education, developing and piloting new BEng programs in priority areas of the SKOLKOVO Innovation Center clusters: IT, Space, Energy Efficiency, Nuclear Technology and Biomed. With the aim of engineering programs modernization innovative technology for curriculum design has been developed on the basis of learning outcomes and CDIO approaches to program development, delivering and evaluation. For the time being the Russian universities – participants of the project are actively working on the BEng programs design and pilot implementation in cooperation with each other and international partners (MIT, ABET, etc.) to ensure high quality of Russian engineering education in priority areas of industrial development. The features of the implemented technology for curriculum design and current results of the project are presented in the paper.

KEY WORDS

Engineering education, BEng program, educational standard, curriculum design.

INTRODUCTION

In 2011 Russian higher educational institutions, including the system of engineering education, moved to the two-tier educational programs: Bachelor’s (4 years) and Master’s (+2 years) in most areas of training based on the Federal State Educational Standards (FSES) of the 3rd generation.

The attitude to the two-tier system of higher education in Russia, especially with regard to Bachelor’s Degree in engineering (BEng), is quite ambiguous on the part of some industrial employers and academics as well. The main reason is doubts regarding the quality of bachelors training for complex engineering activity achieved for 4 years in comparison to 5-year traditional training of Diploma Specialists that form the basis for the national engineering cohort now. Thus, for the time being the development of new FSES-based BEng programs the quality of which is trusted by employers in the industry is one of the key challenges for the Russian technical universities.

Special attention to the problems of engineering education is not accidental. It is fairly logical, since the implementation of the strategy of the Russian economy modernization and technological development significantly depends on the quality of engineering education. To provide the required quality of BEng programs delivering by the Russian universities it is necessary to hold the modernization of programs considering international experience and the best world practice focusing on the CDIO Initiative in particular [1].

THE IDEA OF THE PROJECT

In 2011 National Research Tomsk Polytechnic University (TPU) joined the CDIO Initiative. In 2012 the University introduced a new version of the “TPU Standards and Guidelines on Ensuring the Quality of Engineering Programs” which is based on new FSES and international standards including the CDIO Syllabus and the CDIO Standards. To work out the new national model for BEng programs considering the best world practice in engineering education TPU and SKOLKOVO Foundation initiated the project called “Modernization of Bachelor’s Programs in Engineering in Accordance with International Standards of Engineering Education”.

The main idea of the project is analysis of international standards of engineering education and development of new pilot BEng programs in priority areas of the SKOLKOVO Innovation Center clusters: IT, Space, Energy Efficiency, Nuclear Technology and Biomed. Among the participants of the project there are the leading Russian universities, including TPU (coordinator), National Research Nuclear University (MEPhI), S.P. Korolev National Research Samara State Aerospace University (SSAU), National Research University of Science and Technology (MISIS), Moscow Institute of Physics and Technology (MIPT), National Research University (ITMO) and Higher School of Economics (HSE). The main tasks of the two-year (2012 - 2013) project are as follows:

- Critical analysis of the requirements for professional engineers’ competences in advanced countries and the engineering education international standards including the CDIO Syllabus;
- Analysis and international expertise of the National Professional Standards, requirements of the FSES and Russian employers to the BEng programs in SKOLKOVO priority areas;
- Development of the list of competences for BEng program graduates and international expertise of the list;
- Upgrading of curriculum design technology considering outcome-based approach to structure and content of BEng programs with international accreditation criteria in view;
- Development of recommendations for implementation of BEng programs considering the best world experience, including the CDIO Standards;
- Development of recommendations for the classification of BEng programs in SKOLKOVO priority areas with advanced international experience in view.

The project has started with the International Workshop in Boston (US) with special emphasis placed on identification and comparison of possible approaches to development of undergraduate engineering education considering modern trends in science and technology and current industry challenges. The American model of undergraduate engineering education was introduced by the following interventions: “An ASEE Perspective on Issues and Opportunities in Engineering Education” (Don P. Giddens, ASEE), “A Review of Development and Continuous Improvement of ABET Engineering Criteria 2000” (Joseph L. Sussman, ABET) and “Industrial and Globalization Impacts on Higher Education – An MIT Perspective” (Daniel Roos, MIT), while the European model of first-cycle degree engineering education within the Bologna process framework was exhibited by the following presentations: “Current Status of Bachelor Engineering Programs in Europe” (Gunter Heitmann, SEFI) and “Graduate Attributes in Engineering Bachelor Programs and the Issues of Accreditation, Recognition of Engineering Degrees and Mobility of Engineering Graduates: a European and Global Perspective” (Iring Wasser, ENAEE). The Global CDIO Initiative in engineering education development was expounded in “Rethinking Engineering Education: The CDIO Approach” (Edward Crawley, SkTech) and “CDIO

Implementation: Making It Happen" (Kristina Edstrom, KTH). The comparative analysis of the Association for Engineering Education of Russia (AEER) criteria for accreditation of engineering education and international standards (IEA Graduate Attributes and Professional Competences, EUR-ACE Framework Standards for Accreditation of Engineering Education, CDIO Syllabus) was presented in "Russian Engineering Education: Trends for Development" (Alexander Chuchalin, TPU - AEER). The Workshop was followed by visiting Massachusetts Institute of Technology (MIT) units, including Department of Aeronautics & Astronautics, Space Systems Laboratory, Department of Electrical Engineering and Computer Science, Laboratory of the Computer Science and Artificial Intelligence, Department of Nuclear Science and Engineering, Department of Biological Engineering, etc. The discussions related to approaches to engineering education development were continued during the visits. As a result, the representatives of the Russian universities received a lot of information and food for thought concerning modernization of BEng engineering programs:

- Information Systems and Technologies (ITMO),
- Applied Mathematics (HSE),
- Space Vehicles and Aerospace Technologies (SSAU),
- Electric Power Engineering and Electrical Engineering (TPU),
- Science and Technologies of Materials (MISIS),
- Nuclear Physics and Technology (MEPhI),
- Biotechnology (MIPT, TPU).

THE CURRICULUM DESIGN TECHNOLOGY

For modernization of engineering programs, the participants of the BEng project developed the innovative technology for curriculum design [2]. The ABET two-loop model was modified (Fig. 1) with respect to determining indicators, criteria and methods for assessing learning outcomes immediately after their planning before designing the structure and content of the program.

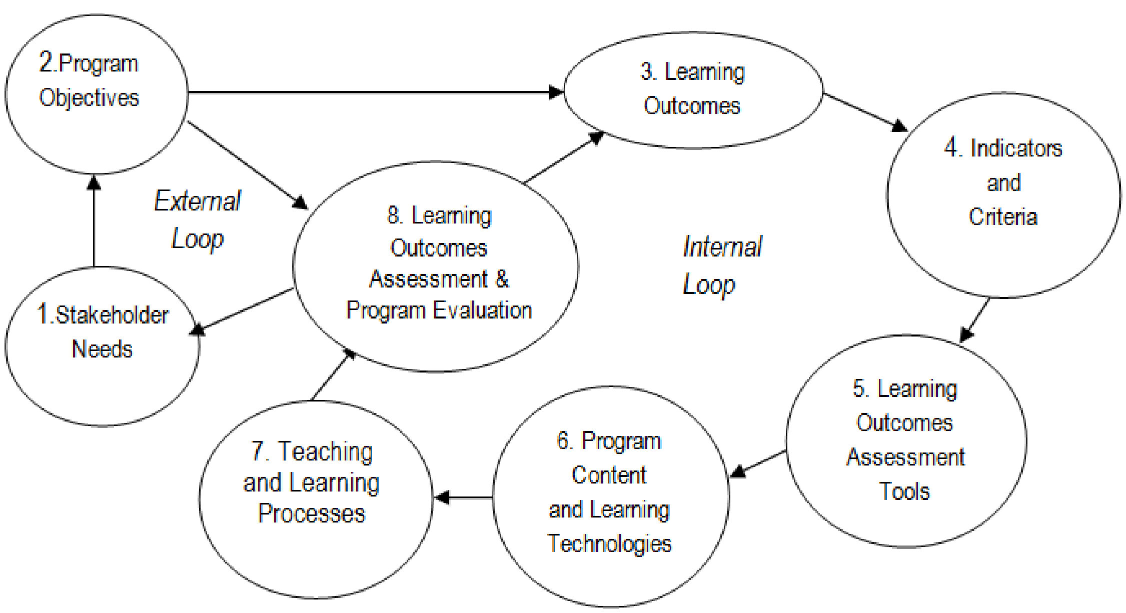

Figure 1. Two-loop model for curriculum design

The modification made it possible to avoid mistakes when planning graduate learning outcomes, namely to plan only the learning outcomes that can be reliably achieved, measured and assessed. Comprehensive learning outcomes were assessed in the credits. On the basis of proper planning of learning outcomes BEng programs can be correctly designed by decompositions of learning outcomes to define structure, content, and teaching and learning technologies. The process of BEng program modernization and redesign started with the revision of program objectives and graduate learning outcomes based on stakeholder needs and requirements of national and international standards of engineering education. It was the first step of the technology for curriculum design, followed by the others.

Step 1. Data collection and analysis to define the program objectives and learning outcomes. The data from the following sources of information are collected and considered to define graduate learning outcomes aligned with stakeholder needs and standards (table 1):

Table 1. Graduate learning outcomes aligned with stakeholder needs and standards

N	*Graduate Learning Outcomes*	*Federal Educational Standards*	*Industry Needs and Requirements*	*AEER Accreditation Criteria*	*ABET Accreditation Criteria*	*IEA Graduate Attributes*	*EUR-ACE Framework Standards*	*CDIO Syllabus*
1	…	…	…	…	…	…	…	…
2	…	…	…	…	…	…	…	…
..								

The CDIO Syllabus (CDIO Standard 2) is used to define detailed learning outcomes for personal, interpersonal, and product and system building skills, consistent with the program objectives [3]. Finally the learning outcomes (LO) are allocated to the program objectives (PO) (table 2).

Table 2. Allocation of learning outcomes to program objectives

	Learning Outcomes											
Program Objectives	PO	LO1	LO2	LO	LO4	LO5	LO6	LO7	LO8	LO9	LO1	…
	1	√	√		√	√	√	√		√		
	2	√	√	√			√	√	√		√	
	…											

Step 2. Specification of indicators, criteria and tools for learning outcomes assessment. During the curriculum design comprehensive (complex) learning outcomes (competences) are decomposed into knowledge, skills and experience on program modules. Monitoring and assessment of student's knowledge, skills and experience are planned on the basis of the development of didactic units (modules) using the appropriate test materials and methods.

However, based on the assessment of the achievement of learning outcome components, in most cases, it is not possible to reliably judge the achievement of complex learning outcomes – competences. An exception may be such forms of learning activity as course project design, research work, the industrial practice and the graduation project approximated to real professional engineering activity.

Analysis of the results of a complex multidisciplinary student activity can be the means of assessing student's professional competences and personal skills using the method of expert assessment of competence on relevant indicators. The criteria for achieving learning outcomes indicators are conditions arising from the definition of competence. The competence is seen as a graduate willingness (attitude, motivation, etc.) to demonstrate the ability (knowledge, skills and experience) for success in any professional or other activity under certain conditions (problems, resources, etc.). Thus, the competence includes three components: the willingness, ability and conditions. Each of the components, in turn, can have a number of attributes. However, it is expedient to limit their number to the so-called "attribute triangle" which reflects the most important points in terms of learning outcomes (Fig 2).

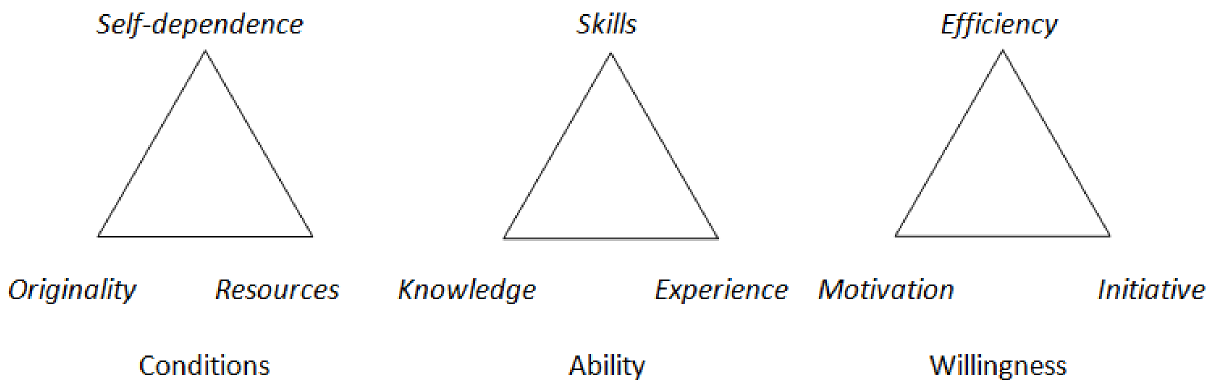

Figure 2. Competence "attribute triangles"

Assessment of learning outcomes on the indicators using the considered criteria may include a quantitative measurement of the indicators. With the application of the described approach to planning of comprehensive assessment of complex learning outcomes, the content of students' course projects, research work, industrial practice and graduation projects can be planned as well.

Step 3. Allocation of ECTS credits to learning outcomes.
According to the Federal State Educational Standards requirements and the AEER accreditation criteria [4], 4-year BEng program is of no less than 240 ECTS credits. A feature of the developed innovative technology for curriculum design is allocation of ECTS credits to learning outcomes before designing the structure and content of the program. As a result, each learning outcome has the credit value that emphasizes its importance in the list of planned graduate competencies (table 3).

Table 3. Allocation of ECTS credits to learning outcomes

Professional Competences (… ECTS credits)							*Transferable skills (… ECTS credits)*			
ECTS Credits	LO1	LO2	LO3	LO4	LO5	LO…	LO10	LO11	LO12	…
	…	…	…	…	…	…	…	…	…	…

A BEng program includes the requirements for professional competences (knowledge and skills in a corresponding branch of engineering, engineering analysis, engineering design, engineering practice and research) and personal or transferable skills (such as individual and team work, communication, professional ethics and social responsibility, engagement into the lifelong learning, etc.). When planning learning outcomes and content of BEng programs, the Standard 1 CDIO is considered. Following the Standard, an engineering program should be based on the principle that engineering product and system lifecycle development and deployment are the appropriate contexts for undergraduate engineering education. *Conceiving-Designing-Implementing-Operating* is a model of the entire product lifecycle.

Step 4. The CDIO Standard 3 introduces requirements to curriculum design. A curriculum should be designed with mutually supporting disciplinary subjects (program modules), with an explicit plan to integrate personal, interpersonal, and engineering product and system building skills. According to the developed and applied curriculum design technology, the following steps should be done:

4.1. Decomposition of learning outcomes into knowledge (K), skills (S) and experience (E).

Table 4. Decomposition of learning outcomes into knowledge (K), skills (S) and experience (E)

Learning Outcomes	*Learning Outcome Components*
LO1	Knowledge (K1.1,K1.2, …) Skills (S1.1, S1.2, …) Experience (E1.1, E1.2, ...)
LO2	Knowledge (K2.1,K2.2, …) Skills (S2.1, S2.2, …) Experience (E2.1, E2.2, ...)
…	…

4.2. Distribution of knowledge, skills and experience by the Federal State Educational Standard sections (Table 5). The learning outcomes are grouped into studies in humanities, economics and social sciences; studies in mathematics and natural sciences; studies in engineering; research work/projects; graduation project.

Table 5. Distribution of knowledge, skills and experience by FSES sections

Studies in humanities, economics and social sciences Knowledge (K1.1,K2.3, K3.4, K7.3, …) Skills (S1.1, S6.5, S8.3, S11.4, …) Experience (E1.1, E4.5, E7.6, E10.2 …)
Studies in mathematics and natural sciences Knowledge (K2.1,K4.5, K7.4, K9.3, …) Skills (S2.1, S3.4, S6.6, S10.7, …) Experience (E4.1, E5.8, E7.2, E11.1 ...)

Studies in engineering Knowledge (K2.5,K3.7, K4.4, K6.1, …) Skills (S5.1, S7.4, S8.2, S10.4, …) Experience (E4.1, E6.7, E8.5, E11.5 ...)
Research work/projects Knowledge (K2.5,K4.7, K5.4, K8.3, …) Skills (S5.1, S7.4, S8.2, S9.3, …) Experience (E5.1, E6.7, E7.3, E11.2 ...)
Graduation project Knowledge (K4.2,K3.7, K4.7, K5.4, …) Skills (S5.1, S5.4, S7.6, S9.2, …) Experience (E4.1, E5.7, E8.3, E11.4 ...)

4.3. Definition of program modules: learning outcome components (knowledge, skills and experience) acquired by the graduates are grouped into the program modules (table 6).

Table 6. Allocation of knowledge, skills and experience to program modules

Studies in humanities, economics and social sciences	
Module 1	Knowledge (K1.1,K2.3, …) Skills (S1.1, S6.5, …) Experience (E1.1, E4.5, ...)
Module 2	Knowledge (K5.1,K7.3, …) Skills (S6.1, S10.5, …) Experience (E3.1, E5.5, ...)
…	…
Studies in mathematics and natural sciences	
Module …	Knowledge (K3.1,K3.3, …) Skills (S2.1, S5.4, …) Experience (E4.1, E6.8, ...)
Module …	Knowledge (K3.3,K4.1, …) Skills (S5.4, S7.6, …) Experience (E6.7, E8.2, ...)
…	…
Studies in engineering	
Module …	Knowledge (K2.1,K4.5, …) Skills (S2.1, S3.4, …) Experience (E4.1, E5.8, ...)
Module …	Knowledge (K2.1,K4.5, …) Skills (S2.1, S3.4, …) Experience (E4.1, E5.8, ...)
…	…

Following the CDIO Standard 4, the module “Introduction to Engineering” is recommended for inclusion into the curriculum as an introductory course within BEng program that provides the framework for engineering practice in product and system building and introduces essential personal and interpersonal skills. The CDIO Standard 5 requires that undergraduate engineering curriculum should include two or more design-build experiences (one at a basic level and one at an advanced level); this should be done when designing a BEng program.

4.4. Allocation of learning outcomes to program modules (table 7).
The program modules should be designed to guarantee the achievement of all the learning outcomes. The learning outcome components of a single module describe in details knowledge and skills that contribute to achievement of learning outcomes by the students and serve as a basis for development of its syllabi.

Table 7. Allocation of learning outcomes to program modules

Program modules	LO1	LO2	LO3	LO4	LO5	LO6	LO7	LO8	LO9	LO10	…
Module 1	+	+	+		+					+	
Module 2	+		+	+	+			+			
…			+				+	+	+	+	

4.5. Allocation of ECTS credits to program modules (table 8).
Each module has the credit value that stresses its importance in the achievement of learning outcomes by the graduates. The curriculum design does not imply any restriction to meet the learning outcomes. For example, the requirements of more than one learning outcome could be satisfied within a single module such as project seminar. It should be noted that such learning outcomes as transferable skills are taught and assessed entirely within a number of modules designed to satisfy the requirements of other learning outcomes.

Table 8. Allocation of ECTS credits to program modules

Program modules	*ECTS Credits*	LO1	LO2	LO3	LO4	LO5	LO6	LO7	LO8	LO9	LO10	LO…
Module 1	8	4	2	2								
Module 2	10	3		3	2				2			
…												
Research work	…	…	…					…				
Graduate Project	…	…	…	…	…	…	…		…		…	…
Total	240	…	…	…	…	…	…	…	…	…	…	…

Step 5. Choice of teaching and learning technologies and types of classes that ensures achievement of learning outcomes. To achieve the learning outcomes, the program providers must be equipped with the appropriate teaching and learning technologies. All known types of classes can be used in program delivery: lectures, seminars, labs, individual and group projects, industrial practices, tutorials, and graduation projects. However, it is advisable to take into

consideration the requirements for graduates' attributes such as the ability to engage in independent learning, to lead a multidisciplinary team, to conduct analytic and experimental research, to use problem-based learning, project-organized learning, activity-led learning, case studies, and both individual and team research projects. The CDIO Standard 6 requires appropriate workspaces and laboratories that support and encourage hands-on learning of product and system building, disciplinary knowledge, and social learning. The CDIO Standard 7 is focused on integrated learning experiences that lead to acquisition of disciplinary knowledge, as well as personal, interpersonal, and product and system building skills. The CDIO Standard 8 recommends teaching and learning based on active experiential learning methods. All these standards are considered at this particular stage of curriculum design.

Step 6. Planning the evaluation of the achievement of learning outcomes and program objectives. The important part of any program is the effective system ensuring assessment of the learning outcomes, evaluation of program objectives achievement and feedback mechanism for continuous program improvement. The institution/department should have a system for monitoring graduates' placement and career development statistics and use these results for further improvement and development of the program. The CDIO Standard 11 is focused on the assessment of students' learning in personal, interpersonal, and product and system building skills, as well as in disciplinary knowledge. The CDIO Standard 12 requires the existence of the system that evaluates programs against twelve CDIO standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement. These standards are very important to be used at curriculum design.

Step 7. Development of the program study plan, modules syllabi, all documentation needed for program delivery and involvement of the faculties well prepared for providing teaching and learning processes of high quality. The CDIO Standard 9 is focused on actions that enhance faculty competence in personal, interpersonal, and product and system building skills, and the CDIO Standard 10 requires actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning. To follow the requirement of these standards, a series of workshops and training seminars for Russian university professors was organized within the project.

CONCLUSION

The above presented technology for engineering curriculum design was developed at Tomsk Polytechnic University. It has been successfully implemented for modernization of TPU engineering programs and was recommended to all Russian universities participating in the project. For the time being the TPU-SKOLKOVO project participating universities are actively working on the BEng programs design and pilot implementation in cooperation with each other and international partners to ensure high quality of Russian engineering education in priority areas of industrial development.

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BIOGRAPHICAL INFORMATION

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