

USING CDIO CONCEPT TO DEVELOP ENGINEERING EDUCATION IN TOMSK POLYTECHNIC UNIVERSITY

A/Prof. Tatyana S. Petrovskaya

National Research Tomsk Polytechnic University, Russia

ABSTRACT

In 2011 National Research Tomsk Polytechnic University (TPU) joined the CDIO Initiative. To modernize engineering educational programs in compliance with CDIO Concept three TPU pilot engineering programs were identified: Electrical Engineering, Chemical Technology, and Mechanical Engineering. Rather than being limited to the traditional curriculum aimed at educating students TPU tries to enhance growing up student complex engineering competence. The emphasis was given to the development of the practice-oriented module designed for engineering students, which will imply gradual development of practical engineering skills. This pivotal module oriented for students' training to engineering profession integrates different types of student design-implement experiences (Introduction to Engineering, projects, research, and course papers) and structures them from 1st to 8th semester within the curriculum.

The paper reviews TPU experience in engineering program design through the example of Bachelor Program in Electrical Engineering.

KEYWORDS

Tomsk Polytechnic University, Engineering Education, CDIO Standards, project-based education, integrated curriculum

BACKGROUND

Strategy and educational policy of National research Tomsk Polytechnic University (TPU) was always based on the integrated development of the scientific and educational processes, fundamental educating of practical engineers, and continuous modernization of its educational programs. TPU was founded in 1896 as Tomsk Technological Institute (TTI) of professional engineers which primary goal was to graduate engineers being able to design and construct industrial enterprises of Siberia, the Urals and the Far East, as well as to discover, to develop and to recover Siberian mineral resources. It has predetermined high level of TPU practical education, orientation of its educational programs to meet the specific targets facing a society and the state.

The choice of the Worldwide CDIO Initiative [1] which concept highly corresponds to the TPU vision of educational programs modernization is a search result of an effective platform for development of educational process in TPU. In 2012 the CDIO Standards have been taken into account while upgrading of the TPU Academic Standard [2] that was a paper subject «Benchmarking of TPU Academic Standard and CDIO Standards in Engineering Education»,

presented by group of TPU authors at the 8th International CDIO Conference in Brisbane (Australia) [3].

In the aforementioned paper analysis results of educational programs TPU according to the CDIO rubrics on example of Electrical Engineering Program are presented. The overall state on compliance of Electrical Engineering Program with CDIO Standards is demonstrated in Figure 1 where numbers of CDIO Standards (1-12) are put on the X-axis and levels of performance (0-5) - on the Y-axis. The graph identifies the area of the program compliance with CDIO Standards as well as finds out trouble spots.

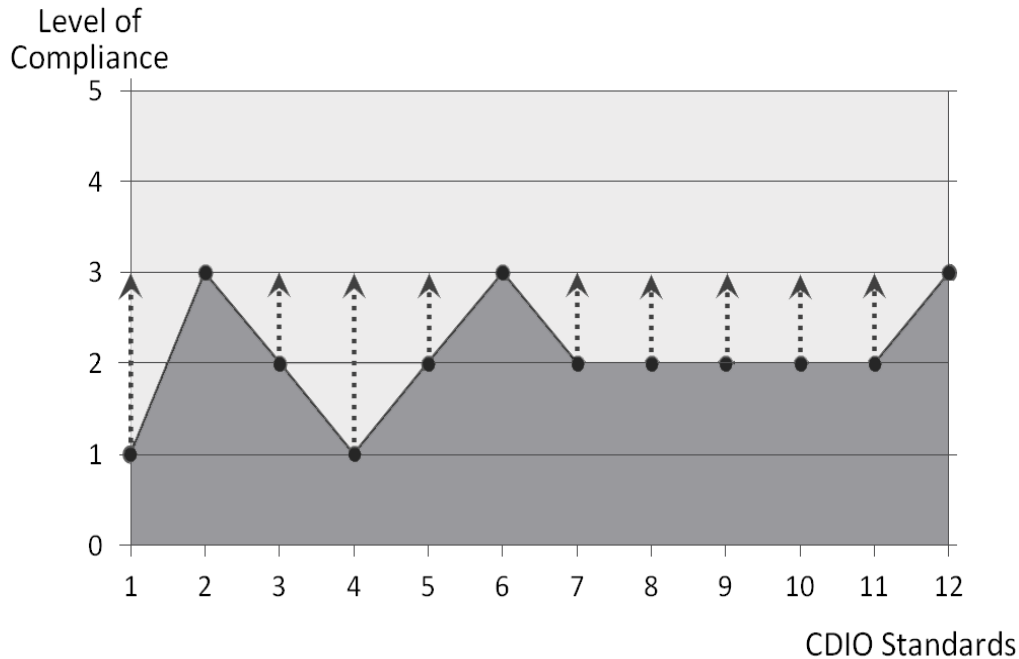


Figure 1. Illustration of the TPU Program compliance with CDIO Standards

The analysis of strengths and weaknesses of TPU engineering educational programs has predetermined their modernization policy.

MODERNIZATION POLICY OF TPU EDUCATIONAL PROGRAMS

Modernization policy of educational programs has been based on self-evaluation of CDIO Standards achievement. Working groups of prospective teachers while designing follow-up activities expecting evidence of high level achievement have worked out a plan for 2012 (Table 1) for each CDIO Standard. All TPU activities on using CDIO Concept for developing engineering education have been classified in three main directions:

1. educational program reform, its structure and content reform;
2. engineering workspaces modernization;
3. enhancement of faculty teaching competence.

Table 1. Directions of TPU educational programs modernization

Direction 1: educational program reform	
CDIO Standard	Event
1	CDIO Concept annexion into educational program
2	Adjustment of goals and learning outcomes in compliance with CDIO Syllabus reflecting the graduate training level in developing new product, process and system building skills
3	Interdisciplinary connection in the course of educational program for best performance of learning outcomes
3	Development of integrated curriculum providing interpersonal and creative skills
4	Development and performance of a program unit "Introduction to engineering"
5	Development of goals and project contents and their tasks for students to gain design-implement experience: <ul style="list-style-type: none"> - at a basic level (2nd, 3rd, 4th terms) for 10 units of academic programs; - at an advanced level (3rd, 4th course year).
11	Planning of learning assessment system integrating interdisciplinary knowledge with personal and interpersonal skills
12	Development of mechanisms and methods of program evaluation
Direction 2: Engineering workspaces modernization	
CDIO Standard	Events
6	Engineering workspaces modernization Standard and logistic support of workspaces in design-implement activity
7	Definition of industrial partners' functions in performance of academic program Upgrading of cooperation with employers Development of criteria of integrated education quality
Direction 3: enhancement of faculty teaching competence	
CDIO Standard	Events
8	Including active learning methods in courses across the curriculum
9	Faculty development at leading industries
10	Organization of seminars and trainings on active learning methods Development of methodical support in introduction of CDIO Concept

It is noteworthy that events of Direction 1 (educational program reform) have become crucial and predetermining for events of other processes. As it seen from Table 1 educational program reform assumes a great set of actions: from goal-setting changes in educational programs and compliance with employers to search for the most effective ways and methods of learning outcomes achievement (development of integrated curriculum, widespread use of project training).

PROGRAM OBJECTIVES AND LEARNING OUTCOMES ADJUSTMENT

The analysis of learning outcomes in Electrical Engineering (version of 2010) in compliance with CDIO Syllabus has shown that some of them aren't formed or formed insufficiently whilst the program realization. In particular, there are such competencies as:

2.3 System thinking

3.1 Team work

4.7 Leading engineering endeavors.

As a result learning outcomes have been represented and in its turn agreed with Federal State Educational Standard of Russian Federation on Electrical Engineering, criteria of the Association for Engineering Education of Russia [4] and CDIO Syllabus. In Table 2 you can see the examples of changes in learning outcomes planned for TPU Electrical Engineering Program.

Table 2. The examples of changes in planning learning outcomes in the course of educational program reform

Learning outcomes in Electrical Engineering Program, 2010	Learning outcomes in Electrical Engineering Program, 2012
Be able to understand and analyze social and economic problems and processes; willingness to use basic methods of humanitarian, social and economic sciences in different ways of professional and social practice.	Be able to demonstrate a complex (systematic) approach to social processes in society, technical processes in industry or enterprise, willingness to intellectual and professional self-education during lifetime.
Be able to use basic laws of Science, mathematical modeling techniques, theoretical and experimental research in professional practice for the purpose of electrical engineering element, object and system modeling.	Be able to apply basic and special mathematical, scientific, socio-economic and professional knowledge for complex engineering practice.

PROJECT BASED LEARNING AS A BASIS FOR INTEGRATED CURRICULUM

Theoretical basis for integrated curriculum development has been identified by specification of integrated curriculum mentioned by Edward F. Crawley, the Professor of Aeronautics and Astronautics and of Engineering Systems at Massachusetts Institute of Technology, USA, the founder and co-director of Management Graduate Program CDIO, at International seminar on innovations and engineering education reforming “The Worldwide CDIO Initiative” [5]: “...and there is the second way when project work is wound into curriculum and each project enables students to realize that each requires discrete knowledge to use...how curriculum is organized, how different curriculum components interact ...”

In organizing project based learning at TPU the principles of CDIO Standard 5 are used:

1. two or more design-implement experiences included into core curriculum;
2. coherent gaining of design-implement experience (increasing complexity of project work);
3. project based learning provides integrated development of engineering, personal and interpersonal skills.

The objective of project based learning in TPU is motivation development and student training to integrated project engineering practice from basic level on out to advanced level of designing by means of integration of learning outcomes in isolated courses and basic shaping necessary for engineering problem solving.

The project based learning at TPU has got the module structure schematically represented in Table 3.

Table 3. The module structure of project training at TPU

Term	Curriculum unit	Learning outcomes
1	Introduction to engineering (theory)	General context of engineering practice, motivation, interest
2-4	Introduction to engineering (project work)	General cultural competencies: communication, work with information, bases of project and team work. Interpersonal skills
4-8	Complex projects (Professional courses)	Professional competencies in compliance with the objectives of particular Academic Program. Interpersonal skills. Leadership.
5-8	Research projects	

Beginning with 2012 educational unit at a basic level “Training to integrated engineering practice” has been included into curricula at bachelor/specialist levels (hereafter – project unit). The project unit is included into variable part of professional courses for all the educational programs in processes and technology at bachelor/specialist levels realizing at TPU beginning with admission 2012. Inclusion of the unit “Introduction to engineering” into curricula (1-4 sessions) enables to implement simultaneously CDIO Standards 4 and 5. The educational unit is worked out for 4 sessions and consists of theoretical part (contact hours) in the 1st session and practice (self-study), project work in the 2nd-4th sessions.

Theoretical part contains four sections:

1. Basic component “Engineering practice and the role of an engineer in the world”, 4 hours.
2. Variable component in specialization (description, history, challenges and achievements, basic employers, etc.), 8 hours.
3. Variable component in skills profile (professional chair history, partnership with industrial enterprises and universities, performance characteristics, etc.), 2 hours for skills profile.
4. Practice – additionally (real/virtual technical visits to research institutes, laboratories...).

The 2nd, 3rd and 4th sessions suppose individual or group/team projects on specialties of the educational program. After completion the basic level of project work a student continues with the next advanced level including class and research projects, course papers and other works performing in 5-8th sessions. Practical training and field internship can be used and are already used as well for pre-project work (for example, material collection) as for individual project with compulsory record of achievement.

One of the main factors for student training to engineering practice at advanced level is TPU worked-out system of strategic partnership with leading industrial enterprises and RECs. This day university’s cross correlation with strategic partners is widespread and includes different aspects of cooperation: employers’ participation in development and realization of educational programs (definition of learning outcomes of intended graduates, traineeships, preparation and graduation paper presentation); cooperation in the sphere of scientific research; enhancement of

material and technical resources; development of laboratories, training centers and other educational centers at partner enterprises.

Different stages of project training mean gradual competence formation. The primary objective of project training at freshman classes at bachelor/specialist level is a formation of personal and interpersonal skills: ability to work with information, ability and willingness to oral and written communication, leadership skills development, individual working efficiency skills, team work skills, display initiative development and many others. The vital issue of project work at a basic level is to increase motivation of undergraduates to specialization choice, social development of engineering practice, forming the general idea about engineering profession. "Senior" bachelors and Master programs students focus on forming professional competencies (depending on Federal State Educational Standard requirements of specialization, TPU Academic Standard and objectives of isolated educational program).

Consequently, the project unit forms a kind of "frame" on which gradually more complicated and special courses are strung from session to session. It enables students to internally perceive academic activity not as a succession of arbitrary varying disciplines and courses badly connected but namely as development process of professional and personal knowledge and skills. Moreover, the given approach enables to find interdisciplinary connection in the course of educational program and is used for forming integrated curriculum.

MODERNIZATION OF ELECTRICAL ENGINEERING PROGRAM STRUCTURE

Organization of project-oriented education as a mechanism for integrated curriculum development has been used whilst TPU Electrical Engineering Program reform.

As in all TPU Academic Programs for admission 2012 the above program curriculum has also contained the unit "Introduction to engineering" with a described structure here. To realize the practical part of educational unit 80 group projects have been worked out and suggested to students.

Moreover, beginning with the 5th session long-term (for 2 sessions) integrated interdisciplinary project for team or individual work is added into curriculum.

Earlier term papers have been developed in the course of isolated discipline and represented as isolated projects concerning specific problems of each discipline (up to 4 term papers or projects). In explicit form interdisciplinary approach has been presented in graduation paper with the necessity to use knowledge of different disciplines for problem solving tasks.

Integrated interdisciplinary project enables students to accumulate engineering skills, team work skills, interpersonal communication, leadership skills development. To complete the project timing resources are planned from those courses where earlier term papers have been developed. Each project has its own manager and advisers (among teachers who have earlier managed the term papers).

The example of the curriculum structure change is shown in Figure 2.

№ п/п.	Название дисциплины	Форма контроля				Кредиты	Объем работы			Аудиторные занятия		
		Экз.	Зач.	КР	КП		Всего	Ауд	Сам	ЛК	ЛБ	ПР
Б3.В5	Управление и организация производства	7	7*	7	7	3	112	48	64	32		16
Б3.В11	Проект (командный или индивидуальный)		7, 8*		7,8	7	92	0	92			
Б3.В.1	"Электромеханика"											
Б3.В.1.2	Технология производства электрических машин	7	7*	7	7	6	160	80	80	24	16	40
Б3.В.1.3	Расчет и принципы конструирования электрических машин	8	8*		8	6	132	66	66	22	16.5	27.5
Б3.В.2	"Электрические и электронные аппараты"											
Б3.В.2.2	Технология производства электрических аппаратов	7	7*	7	7	6	160	80	80	24	16	40
Б3.В.2.3	Теория, основы расчета и конструирования электрических и электронных аппаратов	8	8*		8	6	132	66	66	22	16.5	27.5
Б3.В.3	"Электропривод и автоматика"											
Б3.В.3.2	Теория электропривода	7	7*	7	7	6	160	80	80	24	24	32
Б3.В.3.3	Системы управления электроприводов	8	8*		8	6	132	66	66	22	22	22
Б3.В.4	"Электрооборудование и электрохозяйство предприятий, организаций и учреждений"											
Б3.В.4.2	Электроснабжение потребителей и режимы	7	7*	7	7	6	160	80	80	24	24	32
Б3.В.4.3	Электрооборудование промышленности	8	8*		8	6	132	66	66	22	22	22
Б3.В.5	"Электроизоляционная, кабельная и конденсаторная техника"											
Б3.В.5.2	Основы электроизоляционной и кабельной техники	7	7*	7	7	6	160	80	80	24	16	40
Б3.В.5.3	Расчет и конструирование электроизоляционных систем	8	8*		8	6	132	66	66	22	16.5	27.5

Figure 2. Illustration of changes in the educational program structure

CONCLUSION

TPU engineering programs aims at honing students' practical engineering skills. We consider it highly important to acquire an integrity of all levels and types of students design-implement experience within a curriculum. Furthermore projects carried out by 1-2 year students (basic level projects) should guarantee achievement of student learning outcomes required by higher-level projects.

The second year of TPU CDIO experience (2012) was devoted to the development of the practice-oriented module within the 3 pilot engineering programs. New module structure makes the programs to meet the requirements of both CDIO Standards 4 and 5 by means of:

- including the "Introduction to engineering" course (theory and small projects) into curricula;
- replacing students term papers on different disciplines by interdisciplinary team projects for students in year 3 and 4;
- structuring different types of student project activities (Introduction to Engineering, projects, research, and course papers) according to their learning outcomes from 1st to 8th semester within curricula.

The module ability to be successful in maturing students' engineering skills will depend on:

- faculty competence to guide and assess students project work;
- close interaction between teachers who supervise projects at different stage;
- provision projects of adequate workspaces;
- permanent module evaluation as a base for its improvement.

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BIOGRAPHICAL INFORMATION

Tatyana S. Petrovskaya, PhD, Ass. Professor, Deputy Vice-Rector for Academic and International Affairs of Tomsk Polytechnic University, Russia. Her current research focuses on mechanisms and concepts for educational programs development and evaluation in accordance with international standards and guidelines in engineering education. She coordinates creation of a student-centered environment within university.

Corresponding author

A/Prof. Tatyana S. Petrovskaya
Tomsk Polytechnic University
30, Lenin Ave., 634050, Tomsk,
Russian Federation
+7 3822 563815, pts@tpu.ru



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