Designing the Practice-Oriented Module Within a Curriculum as a Method for Modernisation of Engineering Educational Programme

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ABSTRACT

Purpose:
The paper reviews an approach and experience of Tomsk Polytechnic University (Russia) in upgrading its engineering programmes. TPU aim is to enhance the ability of educational programmes to hone students' practical engineering skills.
Methodology:
TPU used the CDIO approach as the framework of engineering programmes development and outcome-based design of the programmes curricula. The CDIO Concept assumes that the engineering graduates should be able to: Conceive – Design — Implement — Operate complex engineering products as it is demanded by the modern industry.
Findings:
We structured different types of student design-implement experiences (projects, research, course papers) from 1st to 8th semester within the programme curriculum. They became components of the new practice-oriented module. Basic level projects (for students of 1st and 2nd Years) should guarantee achievement of student learning outcomes required by higher-level projects.
Conclusions:
The designed practice-oriented module acquires integrity of different curriculum components and implies gradual development of students' engineering skills.
Value:
Technology of engineering programme improvement within the university modernization strategy is proposed. Detailed structure of the practice-oriented module is presented and conditions for its successful implementation are defined. The paper's audience is university administration, programme designers and faculty.

Keywords: *CDIO, curriculum design, practice-oriented module.*

INTRODUCTION

Strategy and educational policy of National Research Tomsk Polytechnic University (TPU) was always based on the integrated development of the science and education, fundamental educating of practical engineers, and continuous improvement of its educational programmes.

Quality of engineering programmes has always been one of the main TPU priorities. In 2010 TPU developed and approved *«Standards and Guidelines for quality assurance of Bachelor', Master', and Specialist' programs within priority areas of National Research Tomsk Polytechnic University»* (TPU Academic Standard) (2012). It is based on the new generation of Federal Educational Standards (FES) of the Russian Federation and international standards in engineering education (Washington Accord Graduate Attributes, EUR-ACE Framework Standards, etc.). The Academic Standard depicts TPU vision of engineering education objectives and goals. TPU Standard defines the strategy and tasks of educational policy, methodology and stages of programmes design, realization, monitoring, and modernization. Inherently the TPU Academic Standard is a norm of educational programmes' quality which is established and guaranteed by the University.

TPU Academic Standard stipulates the detailed technology of educational programmes design and implementation based on *outcomes-based approach*. The Standard recommends programme designers to align program outcomes with the stakeholders' needs and with the requirements of international standards in engineering education.

TPU *policy of internationalization* assists the deep involvement of the university in partnership with foreign universities, academic consortiums and other associations on higher engineering education (CESAER, CLUSTER, SEFI, EUA, and others). Sharing experience and ideas within this wide network enables the university to pursue the global trends in higher engineering education. Increasing mobility of faculty and students highly contributes to efficient development of TPU graduates' outcomes.

TPU has always worked in close cooperation with employers. It resulted in development of the *strategic partnership networks with leading industrial enterprises*. This day employers are highly involved in development and implementation of TPU programmes (definition of graduates' learning outcomes, traineeships, preparation and presentation of graduation paper, labs and workspaces upgrading, setting up research and educational centers at partner enterprises).

These features of TPU development has predetermined high level of TPU practical education, orientation of its educational programmes to meet international standards in engineering education and the specific targets facing a

society and the state. The above achievements are TPU strength and serve as a fertile background and leaning environment for meeting the challenges facing on engineering education.

CHALLENGES AND LIMITATIONS

Russian education is proud of its strong fundamentals. Though they are not enough to meet the requirements of sophisticated high-tech industry, which expects students to obtain wide disciplinary knowledge as long as an ability to apply it in professional activity. Development of students' practical engineering skills remains a "sore point" of Russian higher education. According to the research study conducted by *M. Dobryakova and I.Froumin* (2010) almost 80% of Russian students never participated in real projects for real customers during their studies. Changes in world economy, society and engineering profession (development of high-tech industry, globalization, etc.) require higher engineering education to grow-up "new generation of engineers" being able not only to deal with advanced technologies and knowledge but also to create new ones. To correspond to this demand universities need to balance cognitive learning of fundamental disciplinary knowledge and acquiring practical engineering skills within curricula. Developing practical skills should not interfere with fundamental knowledge and should comply with university resources.

For gaining the goals university should use its resources in the most effective way. Universities usually complain for lack of *adequate workspaces* and their old-fashioned infrastructure. Access to expensive equipment and supplies may be got via partnerships with advanced enterprises in relevant engineering field. *Faculty resources* (staff competences, teaching and learning methods used) are considered as the most difficult to modify because their development depend on teachers' personal ability and willingness to accept changes. *Time resources* are limited by the official length of programme duration: 4 years for Bachelor programmes and 2 years for Master programs. It is the quality of bachelor graduates especially their ability to complex engineering activity achieved within 4 years instead of 5-year Specialist's studies that raises concerns on a part of industrial employers and academics as well.

These are Bachelor Engineering (BEng) programme graduates who will form the basis for the national engineering cohort in the nearest future. Therefore, this paper describes principles and methods of the practice-oriented module design within TPU undergraduate programmes.

METHODOLOGY FOR A PROGRAMME MODERNIZATION

The TPU strategy of educational programmes modernization is based on the concept of engineering education proposed by *The Worldwide CDIO Initiative*

(2013) and on outcomes-based top-down approach to programme/module design and implementation.

The CDIO Initiative is a worldwide project on reforming of engineering programmes and technologies of their realization. Programmes have to be aimed at training of the engineers, capable to deal with complex engineering products, processes and systems in the modern environment throughout products' lifecycle (Conceiving—Designing—Implementing—Operating). CDIO Collaborators formulated actual requirements to engineering programs (12 CDIO Standards) and to competences of graduates (CDIO Syllabus).

The 12 CDIO Standards address program philosophy (Standard 1), curriculum development (Standards 2, 3 and 4), design-implement experiences and workspaces (Standards 5 and 6), methods of teaching and learning (Standards 7 and 8), faculty development (Standards 9 and 10), and assessment and evaluation (Standards 11 and 12).

The Worldwide CDIO Initiative highly corresponds to the TPU vision of educational programmes modernization. It became an effective platform for development of educational process in TPU. First, TPU defined weakness of its educational programmes using CDIO rubrics for self-evaluation. Then the structure and content of new practice-oriented module were assigned based on the requirements of CDIO Standards 4 and 5. Outcomes-based approach presumed by CDIO Standards 2 and 3 is recommended to use for defining module learning outcomes and to structure them within the curriculum.

Thus, CDIO Concept is used within TPU learning environment as a method to reach a consensus between theory and practice in BEng programmes.

DESIGNING THE PRACTICE-ORIENTED MODULE

Defining the programme weakness

The first TPU step in CDIO implementation was carrying out the self-evaluation of 3 pilot engineering programmes (Chuchalin A.I. *et al*. 2012). The self-evaluation results identified the area of the programmes compliance with CDIO Standards as well as finds out trouble spots. The failures became TPU departure points in aligning the level of compliance with CDIO Standards and prescribed TPU start-up activities to meet this goal.

The lowest TPU level of performance was in Standards 1and 4. CDIO Standard 1 assumes adoption of the principle that product, process, and system lifecycle development and deployment — Conceiving, Designing, Implementing and Operating — are the context for engineering education. To correspond to CDIO Standards 1 TPU has upgraded its Academic Standard by added the CDIO Standards requirements.

According to CDIO Standard 4 a programme curriculum has to include an introductory course that provides the framework for engineering practice in product, process, and system building, and introduces essential personal and interpersonal skills. Following the CDIO Standard 4, the module "Introduction to Engineering" was elaborated and recommended for inclusion into the curriculum Primarily this module was considered to comprise a one year course. The idea of the course was to combine theoretical knowledge on the context of engineering profession with the first design-implement experience for TPU freshmen. So the course was extended for 2 years (1-4 semesters) and became a module including theory and project student work.

During elaboration of "Introduction to Engineering" it became obvious that interdisciplinary connections are strong within a programme module (Humanities, Economics, Natural Sciences, etc.) but remain very weak for subjects from several modules. Furthermore, students' course projects were conducted within a separate subject and its specific issues. According to the curricula students' knowledge and skills from these isolated subjects were "to meet" on senior years of study only. In other words an explicit interdisciplinary approach has been presented when doing research or graduation project. Thus, the TPU task was to combine different types of students' design-implement experiences within practice-oriented module which will imply gradual development of practical engineering skills.

Defining the module structure

The second year of TPU CDIO experience (2012) was devoted to the development of the practice-oriented module within the 3 pilot BEng programmes.

In designing the practice-oriented module at TPU the principles of CDIO Standard 5 were 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.

Elaborated practice-oriented module named as "Training to integrated engineering activity" consists of 5 units, 2 of them related to the basic level of project work and the other 3 prescribe projects at the advanced level (see Table 1).

Beginning with 2012 the "Introduction to Engineering" has been included into curricula of all the BEng programmes as a unit of the practice-oriented module. The unit lasts 4 semesters and consists of theoretical part in the 1st semester and small projects in the 2nd-4th semesters.

Table 1. Structure of the practice-oriented module within TPU programmes curricula

Level of project work	Semesters	Module unit	CDIO Syllabus Learning outcomes (focus on)
basic	1	Introduction to Engineering (theory)	2.1., 2.2., 2.4.,
	2-4	Introduction to Engineering (project work)	2.3., 3.1, 3.2., 4.1.
advanced	5	Complex Project (engineering or research)	2.5.,4.3-4.8.
	5-8	Research projects, course papers, internship	
	8	Graduation Project	

Theoretical unit includes four sections:

1. Core component "Engineering profession and the role of an engineer in the world",
2. Specialized component depending on field of engineering (description, history, challenges and achievements, basic employers, etc.),
3. Specialized component depending on engineering profile (history of TPU department on corresponding engineering profile, partnership with industrial enterprises and universities, performance characteristics, etc.),
4. Practical component (real/virtual technical visits to research institutes, laboratories, etc.).

Upon completion the theoretical unit students are required to write an essay. Topics chosen by students, such as "My future profession", "An engineer who impressed me", etc. are considered to allow students to express their opinions on engineering and/ or imagine themselves as engineers in the prescribed situation.

The 2nd, 3rd and 4th semesters suppose individual or group/team projects on the field of student study. Student is allowed to participate in projects related to different fields of engineering that he could self-define his priorities for future specialization.

After completion the basic level of project work a student continues with the next advanced level including engineering and research projects, course papers, internship, and other works performing in the 5-8th semesters.

Moreover, beginning with the 5th semester a long-term (for 2 sessions) integrated interdisciplinary project for team or individual work (called as «complex project») is added into curriculum. The complex project has integrated course papers and

projects which were primarily conducted within isolated subjects and acquired their workload.

Each project is supervised by a group of teachers who have earlier managed the course papers. It makes teachers of different subjects work together within the project design and implementation. Furthermore, they are forced to agree upon the content of each subject as well as determine project co- and pre-requisites.

New module makes the programmes to meet the requirements of both CDIO Standards 4 and 5 by means of:

- including the "Introduction to engineering" sub-module (theory and small projects) into curricula;
- replacing students term papers on separated subjects by interdisciplinary team projects for students in years 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 designed practice-oriented module forms a kind of "pivot" on which gradually more complicated and special courses are strung from semester to semester. It enables students to perceive educational process not as a succession of varying subjects and courses badly connected but namely as a coherent process of engineering knowledge and skills development.

Module learning outcomes

The process of learning outcomes definition starts at the top, and module learning outcomes are determined by the distribution of programme learning outcomes over all components of a curriculum.

The general objective of the practice-oriented module is student motivation for and training to engineering profession from basic to advanced level by means of integration of learning outcomes provided by different subjects. Programme designers are to specify the module learning outcomes according to the programme objectives and types of engineering activity, which a graduate is educated for.

Different stages of students project work mean gradual learning outcomes development.

The basic level projects have dual-purpose task. On the one hand they have to prepare student for achieving of learning outcomes required for projects of higher level, on the other hand - to adapt yesterday's secondary school graduates to the development of engineering skills. The vital issues of basic level projects are creation of student self-learning culture and development of student motivation and interest to future profession. Thus, the primary learning outcomes for basic

level projects are the personal and interpersonal skills stipulating in the Sections 2 and 3 of CDIO Syllabus (Crawley E.F. *et al*. 2011). It is also important to form students ' understanding of the product lifecycle, from the first year of study, and some combination of "conceive-design-implement-operate" skills is to be determined as learning outcomes for basic level projects.

The advanced level projects focus on accumulating and maturing of student engineering skills and should be fully correspond to the nature of graduates' future engineering activity. Their learning outcomes cover graduate skills related to all stages of product lifecycle prescribed by the Sub-Sections 4.2.-4.6. of CDIO Syllabus.

Distribution of CDIO Syllabus learning outcomes over the module units given in Table 1 is no more than a recommendation. Module designers are advised to use the CDIO Syllabus while determining the detailed learning outcomes for graduates' personal, interpersonal, and product and system building skills.

CONCLUSION

The described practice-oriented module is recommended to TPU program designer as a framework for organizing student design-implement experiences within curriculum. The module learning outcomes as well as the projects content needs to be detailed depending on specific objectives and needs of each BEng programme.

The new module strengthens a practical orientation of educational programs without prejudice to theoretical knowledge. We hope that the upgraded curriculum will allow forming practical engineering skills in accordance with the inquiries of the modern industry.

Implementation of the new curricula begins from 2013-2014 academic year. 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.

TPU next step will be development of methodical documentation for new practice-oriented module: requirements to projects, instructions for students, tutorial recommendations, assessment methods, etc. The special attention will be paid to the basic level projects as they lay the foundation for formation of engineering skills.

We plan to design questionnaires for students, faculty and employers to estimate influence of the new module on quality of students training. Besides, it will promote process of continuous improvement of TPU educational programmes.

Given approach enables to find interdisciplinary connection in the course of educational program and is used for elaborating integrated curriculum.

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