RAEE ACCREDITATION CRITERIA AND CDIO SYLLABUS: COMPARATIVE ANALYSIS

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ABSTRACT

The paper focuses on the comparative analysis of the Russian Association for Engineering Education (RAEE) accreditation criteria and CDIO Syllabus requirements. The RAEE is responsible for professional accreditation of engineering programs in Russia and is striving for international recognition of the Russian accredited programs and graduates' qualifications. The CDIO INITIATIVE is an innovative educational framework for producing the next generation of engineers. The comparative analysis of CDIO Syllabus and RAEE Criterion 5 for accreditation of Bachelor engineering educational programs in Russian technical universities is worth considerable attention. The analysis shows entire consentaneity or principal equivalence of the RAEE Criterion 5 requirements for Bachelor's competencies and CDIO Syllabus topics. Special emphasis is placed on both RAEE Criteria and CDIO Syllabus when designing curriculum for engineering programs at Russian HEIs. The paper aims to illuminate the experience of National Research Tomsk Polytechnic University. Advancement of engineering education is a challenging task to implement the strategy of economy modernization and technological development in Russia subsequently bringing it to the best international standards.

KEYWORDS

Engineering education, accreditation criteria, quality, learning outcomes.

INTRODUCTION

Engineering profession based on knowledge is getting more complex and innovative in the postindustrial society thus making engineering activity more diverse and multifunctional. It embraces development, design, production and operation of technical objects and systems and is based on profound fundamental and applied multidisciplinary knowledge and innovation. Moreover, it is aimed at development of new technologies that create new social and economic demand and are efficient and highly competitive.

Training of technical experts capable of solving complex engineering tasks is ensured by the adequate level system of engineering education. The system is efficient only if the real sector of economy, employers and professional engineering society with due consideration of state-of-the-art situation in science and technology define the standards of engineering education and set the tasks for universities to train specialists ready to respond to multiple challenges. It is the professional society that is competent to assess the quality of specialists' training for engineering activity and the degree of its conformity to the recognized standards.

Thus, the system of engineering education and its unbiased assessment emerges as the result of interaction of universities with the society and technological and scientific community. In a great number of countries, tools for professional accreditation and certification function successfully and consistently, resulting in a two-stage system of quality assurance of graduates' training and professional qualifications development.

The first stage of the system is the evaluation of educational programs quality by means of professional accreditation. The second stage implies assessment by practicing experts by the use of certification and registration of candidates as professional engineers. The corresponding procedures are implemented by national and usually nongovernmental professional organizations including the agencies for educational programs accreditation and specialists' certification: ABET (USA), ECUK (UK), Engineers Canada (Canada), JABEE (Japan), Engineers Australia (Australia), etc. International standards for quality of engineering programs are defined today by two reputable organizations: the Washington Accord, a participant of International Engineering Alliance (IEA), and the European Network for Accreditation of Engineering Education (ENAEE).

The Washington Accord unites accrediting agencies in 14 countries as full members and 6 provisional members, including the Russian Association for Engineering Education (RAEE). The Washington Accord members (professional organizations) evaluate the quality of engineering programs using the agreed criteria and recognize the substantial equivalence of the accredited engineering programs provided by the Washington Accord signatories on the basis of the designed engineering education standards (IEA Graduate Attributes).

Inspired by the Bologna Process, the European Network for Accreditation of Engineering Education was founded in 2006 aiming at transition to the tier system in European higher education. ENAEE members implement the scheme based on the accreditation criteria for two-cycle engineering programs in Higher Education Institutions (HEIs) agreed with EUR-ACE Framework Standards for Accreditation of Engineering Programs. For the time being, the ENAEE has authorized accrediting agencies in 8 countries, among them Germany, France, UK, Ireland, Italy, Portugal, Turkey, and Russia (RAEE). In the foreseeable future the engineering organizations in Spain, the Netherlands, Switzerland and other European countries plan to join the ENAEE family.

The EUR-ACE Standards conform to the Framework for Qualification of the European Higher Education Area (EHEA) and include the requirements for the engineering programs of the First (FC) and Second Cycles (SC). The development of the EUR-ACE system is accomplished with the active participation of the European Federation of National Engineering Associations (FEANI) that certifies and registers engineers in Europe awarding the EURING Label. Since 2008 Russia is represented in FEANI by the Russian Union of Scientific and Engineering Associations (RUSEA).

THE RAEE CRITERIA

The Russian Association for Engineering Education is a public organization uniting the human resources of higher education, engineering profession and technical sciences within 60 regions of the Russian Federation. The RAEE Accreditation Center was established in 2002 (http://www.ac-raee.ru). The RAEE Accreditation Board consists of reputable representatives of academia, science, industry and professional organizations.

The RAEE activity on development of the system for engineering programs accreditation is supported by employers representing various spheres of industry and a number of professional associations and unions [1]. The RAEE cooperates with the Russian Chamber of Commerce & Industry, the Russian Academy of Engineering Science, the Russian Academy of Education, the Russian Academy of Science, the Russian Union of Industrialists & Entrepreneurs, the Russian Union of Scientific and Engineering Associations and others.

Over 200 engineering programs in Russia and Kazakhstan have been accredited by the RAEE Accreditation Center (RAEE AC), including those awarded the EUR-ACE Label [2]. The evaluation criteria developed by the RAEE AC are based on the best traditions of the national higher education and international experience of engineering education quality assurance with special emphasis placed on graduates' competences and learning outcomes [3].

In 2011 Russia entered a new stage of university education modernization supported by the introduction of the new Federal State Educational Standards (FSES) and mass transition to two-cycle system of higher education: First Cycle Degree (FCD) - Bachelor (4 years) and Second Cycle Degree (SCD) - Master (2 years). The system still includes 5-year educational programs of Specialists' training (integrated programs leading to SCD) in a number of disciplines. The considerable changes in the Russian system of engineering education seem quite plausible, i.e. the reduction of the tutorial by one year (transition from 5-year Diploma Specialists' programs to 4-year Bachelors' programs in the majority of disciplines), which is still under debate.

The RAEE modified the criteria for accreditation of engineering programs taking into account the new FSES and membership in international organizations (the Washington Accord and ENAEE). With the priority given to international engineering agreements, engineering profession and the engineering community playing the key role in engineering programs evaluation, the RAEE initiated the revision of criteria for professional accreditation in order to make it consistent with those of the world leading engineering organizations. These changes resulted in elaboration of the new set of the outcome-based criteria compatible with those existing in the Washington Accord signatories and ENAEE members [4]. The revision was encouraged by the leading Russian universities that actively participated in elaboration of the new approaches to quality assurance.

For the time being, the RAEE accreditation criteria are grouped as follows:

1. Program Objectives (sets the requirements for formulating the objectives of the educational programs: the program objectives are formulated on the basis of the demands of key consumers and are agreed with the HEI's mission, state educational standards of higher education; the objectives should be shared by the community, should be published and open for all the stakeholders).
2. Program Content (sets the requirements for the content of the educational program: a program should hold firmly stated learning outcomes agreed with program objectives, satisfy the requirements for the curriculum structure and for the correlation between the volumes of disciplines cycles).
3. Students and study process (sets the requirements for the learning process and student contingent: study process should ensure the possibility of achieving the learning outcomes by every graduate of the program; a program should possess the tool for continuous control for curriculum performance and the feedback for its improvement).
4. Faculty (sets the requirements for the teaching staff ensuring the delivery of the educational program, the level of its qualification; participations of the teaching staff in pedagogic and scientific research).
5. Professional qualification (sets the requirements for the learning outcomes – knowledge, skills and experience that student should gain by graduation: each learning outcome should ensure the achievement of at least one program objective; learning outcomes should be particular for every educational program and be measurable).
6. Facilities.
7. Information infrastructure.
8. Finance and management (sets the requirements for the resource base of the program: available resources should correspond to program objectives and ensure the learning outcomes achievement by every graduate).
9. Graduates (sets the requirements for the HEI' work with the educational program graduates: the system for employment analysis, demand, career coaching and

continuous professional development; received data should be used for further upgrade of the educational program).

The RAEE significantly modified Criterion 5 (Professional qualification) for accreditation of FCD and SCD engineering programs. It is supposed that a Bachelor graduate (a graduate of the FCD engineering program) should be trained for complex engineering activity, while both a Master and a Specialist (the graduates of the SCD engineering programs) should be trained for innovative engineering activity.

Characteristics and notions of complex and innovative engineering problems can be observed and explained in a great number of ways. The RAEE requirements set for the Bachelor, Master and Specialist competencies in the area of engineering and technologies are shown in Table. 1. Comprehensive and comparative analysis shows that new RAEE requirements set for Bachelor's competencies in the area of engineering and technologies meet the requirements of the IEA Graduate Attributes. The requirements set for engineering Master's and Specialist's competencies are compatible with the EUR-ACE Framework Standards for Accreditation of Engineering Programs (SCD engineering programs).

Table 1
The RAEE requirements set for the Bachelor's, Master's and Specialist's competencies

FCD (Bachelor)	SCD (Master, Specialist)
1. Professional competences	
1.1. Fundamental Knowledge	
Apply comprehensive knowledge of mathematics, natural and social sciences, economics and engineering in the interdisciplinary context of complex engineering activities.	Apply in-depth knowledge of mathematics, natural and social sciences, economics and engineering in the interdisciplinary context of innovative engineering activities.
1.2. Engineering Analysis	
Identify and solve the problems of complex engineering analysis applying comprehensive knowledge and modern analytical methods and models.	Identify and solve the problems of innovative engineering analysis in the conditions of uncertainty applying in-depth knowledge, analytical methods and complex models.
1.3. Engineering Design	
Design solutions for complex engineering problems applying comprehensive knowledge and methods to achieve the optimal results to meet defined and specified requirements.	Design solutions for innovative engineering problems applying in-depth knowledge and original methods to achieve the advanced results in the conditions of uncertainty.
1.4. Investigation	
Conduct investigations of complex engineering problems including information search, experiment, and data interpretation applying comprehensive knowledge and modern methods to achieve required results.	Conduct investigations of innovative engineering problems in the conditions of uncertainty including critical analysis of data, complex experiment, interpretation and decision making applying in-depth knowledge, and original methods to achieve required results.
1.5. Engineering Practice	
Select and use appropriate resources,	Create and use appropriate resources,

equipment and tools for complex engineering practice taking into account economic, environmental, societal aspects and other limitations.	equipment and tools for innovative engineering practice taking into account economic, environmental, societal aspects and other limitations.
1.6. Specialization and labour market orientation	
Be trained to invest knowledge, skills, time and effort for complex engineering activities as required by potential employers and follow their corporate culture.	Be trained to invest knowledge, skills, time and effort for innovative engineering activities at enterprises and companies that are potential employers and follow their corporate culture.
2. Transferable and personal competences	
2.1. Project and Financial Management	
Apply comprehensive knowledge of project management and business practice for complex engineering activities including risk and change management.	Apply in-depth knowledge of project management and business practice for innovative engineering activities including risk and change management.
2.2. Communication	
Communicate effectively for complex engineering activities with engineering community and society at large in native and foreign languages.	Communicate effectively for innovative engineering activities with engineering community and society at large in native and foreign languages.
2.3. Individual and Team Work	
Function effectively both as an individual and as a member of a team in multidisciplinary settings, share responsibilities and capabilities to solve complex engineering problems.	Function effectively both as an individual and as a member or leader of a team and in multidisciplinary and international settings, share responsibilities for a team work to solve innovative engineering problems.
2.4. Professional Ethics	
Demonstrate personal responsibility and commitment to professional ethics and norms of engineering practice.	Demonstrate responsibility for both individual and team work and commitment to professional ethics and norms of engineering practice.
2.5. Societal Responsibility	
Demonstrate knowledge and understanding of the legal, societal and cultural, environmental and health and safety issues relevant to complex engineering practice.	Demonstrate in-depth knowledge of the legal, societal and cultural, environmental and health and safety issues relevant to innovative engineering practice.
2.6. Lifelong Learning	
Recognize the need for, and have the ability to engage in lifelong learning and professional development.	

Today Russian universities undergo mass transition to the level system of higher education in accordance with FSES. Thereupon, the task of crucial importance is modernization of Bachelor degree engineering programs considering the experience of the countries which successful implemented the level system of university education.

CDIO SYLLABUS VS RAEE CRITERIA

Over the last decade, a broad sense has evolved that there is a need to create a new vision and concept for undergraduate education (Bachelor level). Since 2000, a number of universities worldwide guided by MIT have been engaged in an organized international educational initiative focused on the CDIO approach [5]. The first fundamental principle of the approach is that the Conceiving-Designing-Implementing-Operating of products, processes and systems should be within the authentic context of engineering education.

The second principle of the CDIO approach efficiency is that an engineering program should set specific and detailed learning outcomes. The CDIO Syllabus classifies learning outcomes into four high-level categories: technical knowledge, personal and professional attributes, interpersonal skills, and the skills specific to the engineering profession (Table 2).

Table 2
The CDIO Syllabus engineering graduates learning outcomes

1. Disciplinary knowledge and reasoning 1.1. Knowledge of underlying mathematics and science 1.2. Core fundamental knowledge of engineering 1.3. Advanced engineering fundamental knowledge, methods and tools	3. Interpersonal skills: teamwork and communication 3.1. Teamwork 3.2. Communications 3.3. Communications in foreign languages
2. Personal and professional skills 2.1. Analytical reasoning and problem solving 2.2. Experimentation, investigation and knowledge discovery 2.3. System thinking 2.4. Attitudes, though and learning 2.5. Ethics, equity and other responsibilities	4. Conceiving, designing, implementing, and operating systems in the enterprise, societal and environmental and attributes context 4.1. External, societal and environmental context 4.2. Enterprise and business context 4.3. Conceiving, systems engineering and management 4.4. Designing 4.5. Implementing 4.6. Operating

The comparative analysis of the CDIO Syllabus (Table 2) and the RAEE Criterion 5 for accreditation of Bachelor degree engineering programs in Russian HEI (Table 1) is worth considerable attention. The analysis shows entire consentaneity (**x**) or principal equivalence (**o**) of the RAEE Criterion 5 requirements for Bachelor's competencies and the CDIO Syllabus topics (Table 3).

The entire consentaneity of the CDIO Syllabus requirements and the RAEE Criterion 5 is the case for greater part of the positions: fundamental mathematics and science, core engineering knowledge, Bachelor's competences in design, research, project and financial management, communications, individual and team work, professional ethics and social responsibility.

The requirements of the RAEE Criterion 5 regarding the Bachelor's readiness for engineering analysis (1.2) actually coincides with the CDIO Syllabus requirements for their abilities for analytical reasoning and problem solving (2.1) and for system thinking (2.3).

Table 3
Matrix of the CDIO Syllabus and the RAEE Criterion 5 comparative analysis

CDIO / RAEE	1.1	1.2	1.3	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	4.1	4.2	4.3	4.4	4.5	4.6
1.1	X	X	X														
1.2				O		O								O			
1.3															X		
1.4				O	X												
1.5			O											O	O	O	O
1.6														O	O	O	O
2.1													X				
2.2										X	X						
2.3									X								
2.4								X									
2.5												X					
2.6							O										

The RAEE Criterion 5 requirements for engineering practice (1.5) and employer orientation (1.6) agree with basic requirements of the CDIO Syllabus regarding Bachelor's readiness for solving the tasks of conceiving, designing, implementing and operating the products of engineering activity (4.3 - 4.6). The RAEE Criterion 5 requirements for lifelong learning (2.6) correspond to 2.4 of the CDIO Syllabus (attitude, thought and learning).

Table 3 presents the comparative analysis outcomes of the CDIO Syllabus basic requirements with the RAEE Criterion 5 for accreditation of Bachelor degree engineering programs. A range of additional requirements to engineering education content with regard to leadership and entrepreneurship were introduced in the second version of the CDIO Syllabus, at the same time these requirements in the RAEE Criterion 5 mostly refer to Master's and Specialist's competences.

The advantage of the CDIO Syllabus is that in comparison with the requirements of engineering organizations accrediting educational programs in universities (including the RAEE Criterion 5), the requirements are subdivided in four levels. It enables the educational programs developers to implement the outcome-based approach efficiently, i.e. to define in details the additional data for program design and to set the tasks for professors responsible for modules and disciplines of the program.

TPU EXPERIENCE

In the context of transition of the Russian higher education to FSES, the new wording of the Russian Federation Law "On Education" grants significant academic freedom to leading universities (including Federal Universities and National Research Universities). It enables these universities to develop and implement educational programs on the basis of their own Educational Standards and Requirements (Russian Federation Law "On Education" a.7, i.2

as revised in 2009). So, the Universities' Educational Standards could combine the FSES requirements with those suggested by international standards for engineering education, in particular the CDIO Syllabus and the CDIO Standards.

National Research Tomsk Polytechnic University (TPU) introduced its own Educational Standard developed on the basis of FSES and international standards of engineering education requirements (criteria of international accreditation of educational programs and criteria for certification and registration of professional engineers in international registers).

In 2010 TPU put into action The Standards and Guidelines for Quality Assurance of Bachelor's, Master's and Specialist's Programs in Priority Areas. TPU Educational Standards-2010 develop and supplement FSES requirements with those of international certifying and registering organizations (EMF, APEC Engineer Register, FEANI) to professional engineers competences (defining program objectives), criteria for international accreditation of engineering programs (WA, EUR-ACE), and the RAEE Criteria for Accreditation of Programs in Engineering and Technology (defining learning outcomes).

TPU Educational Standards-2010 envisage Outcome-Based Approach to design, delivery and quality assurance of educational programs, creation of Student-Centered Education Environment, implementation of ECTS for assessment of learning outcomes and program modules, Rating System for students' learning outcome assessment, as well as Liberal Organization of studies with special emphasis placed on students' individual work (Learning VS Teaching) and Active Education Technologies. TPU Educational Standards-2010 serve as the basis for the Integrated System for Quality Management of Education at university compliable with Standards and Guidelines for Quality Assurance in the European Higher Education Area and ISO 9001:2008 Quality Management Standards.

Tomsk Polytechnic University regularly subjects its educational programs to external evaluation by international experts. In 2005 and 2008 TPU's Specialist's program in Computer Engineering was accredited by the Canadian Engineering Accreditation Board (CEAB). In 2006 the Bachelor's program in Electrical Engineering was accredited by the US Accreditation Board for Engineering and Technology (ABET). From 2003 to 2011 about 30 FSD and SCD TPU engineering programs successfully passed RAEE accreditation, including 25 programs awarded EUR-ACE Labels and listed in ENAEE and FEANI registers.

Modernization of the Russian engineering education with international standards in view triggered implementation of Engineering Curricula Design Project aligned with EQF and EUR-ACE Standards (511121-TEMPUS-1-2010-1-DE-TEMPUS-JPCR) [6]. TPU acts as project coordinator of Russian universities; N.E. Bauman Moscow State Technical University, Saint-Petersburg State Polytechnic University, ENAEE, the European Society for Engineering Education (SEFI) and a number of European universities are among project participants.

In 2011 National Research Tomsk Polytechnic University joined the CDIO Initiative. In 2012 TPU introduced a new version of Educational Standards which takes into account the CDIO Syllabus and the CDIO Standards. To work out the new national model of Bachelors in Engineering and Technology corresponding to the best international standards and aimed at the development of globally competitive industry, TPU initiated the project called "Modernization of Bachelor's Programs in Engineering in Accordance with International Standards of Engineering Education" [7]. The project is financed by Skolkovo Foundation with the participation of leading Russian universities of technology: TPU (coordinator), National Research Nuclear University (MEPhI), S.P. Korolev National Research Samara State Aerospace University, National Research University of Science and Technology (MISIS), Moscow Institute of Physics and Technology (MIPT), St. Petersburg National

Research University of Information Technologies, Mechanics and Optics (ITMO) and Higher School of Economics (HSE).

The main tasks of the two-year (2012 - 2014) project are as follows:

- Critical analysis of the engineering education international standards including the CDIO Syllabus and requirements for competences of professional engineers in advanced countries;
- Analysis and international expertise of the national professional standards, requirements of the FSES and national employers to the Bachelor's programs in Skolkovo priority areas of engineering and technology;
- Development of list of competences for the graduates of engineering Bachelor's programs and their international expertise;
- Upgrading of concept and technology for structure and content of Bachelor's engineering programs with international accreditation criteria in view;
- Development of recommendations for educational programs implementation taking into account the best world experience, including the CDIO Standards;
- Development of recommendations for the classification of engineering educational programs in Skolkovo priority areas considering advanced international experience.

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