

Elite Engineering Education Programme in Tomsk Polytechnic University – the way to attract talented students into Engineering

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Abstract—The paper describes the concept of Elite Engineering Education Programme (EEEP) adopted by Tomsk Polytechnic University (TPU) that provides prospective students with additional training aimed at improving their general and professional awareness and developing their capability to adapt to the current highly volatile engineering environment. The paper states and focuses on the tasks for developing and implementing the Programme that include developing the EEE concept itself, creating a student selection system and a teacher selection system, and designing a programme that allows its students to meet the requirements of the modern engineering labor market. An overview of the system currently operational in TPU is provided, and the current composition of the program's curricula is presented as a table. A conclusion is made reasoning the EEEP as a viable means of attracting talented students into engineering.

Keywords—*engineering education; competencies; additional education; educational programs; engineering students; curriculum*

I. INTRODUCTION

During the recent centuries the area of engineering has been steadily growing in importance worldwide, calling for more and more people to develop, operate, and maintain new technologies, thus making itself a promising labor market. But the current volatile situation in the world's economy and the never-ending avalanche of newer and newer technologies, as well as realization of the inevitability of long and hard work and study that will be getting harder and harder, might challenge one's decision to choose the path of engineering, adding to the problems faced by the higher education institutions (HEIs) of today.

Presently, Russia's higher education system faces the following:

- the quality of school education in Russia is decreasing¹, the result being the tangible necessity of

introducing compensatory courses that would allow yesterday's school students to compensate for the gaps in their education. Talented students are simply lost within such groups;

- HEIs produce large numbers of economists, law specialists, and managers, but the actual situation makes it clear that economical measures alone are insufficient to modernize Russia's engineering sector;
- graduates with engineering majors clearly do not satisfy the requirements of the modern society due to their considerably narrow specialization and lack of soft and interdisciplinary skills.

The latter is corroborated by the list of learning outcomes that would shape an engineering leader fit for innovation and entrepreneurial activities developed by members of CDIO Initiative [1]. Comparing this list to the list to the outcomes provided by common general educational programmes (GEPs) in engineering makes it obvious that these GEPs do not fully cover it or, frequently, do not cross at all.

Ken Robinson, one of the world's leading education specialists, offered an interesting analogy comparing the present education system to a fast food industry of sorts, where everything is built on standards and guarantors. Taking this into account, education model of the future should resemble a Michelin restaurant, i.e. to be unique and produce the number of elite technical specialists that is small but capable of high-impact engineering and entrepreneurial activities. This new approach to education should leave standards behind in favor of maximum uniqueness and creative free-will [2]. This necessitates the selection of best HEI students to offer them additional training programmes. For example, a system like this is currently active in National Research Tomsk Polytechnic University (TPU) and is called the Elite Engineering Education Programme (EEEP).

¹ "From 80 to 90 percent of prospective students entering some of the engineering majors are C-graders, judging by the Unified State Exam." Report by Yaroslav I. Kuzminov, rector of NRU HSE, at the 2nd International Conference "Universities and the State".

Elite engineering specialists have to undergo additional training that is connected with conceptions of the future. This is especially important today, as everything in our world is moving very fast: knowledge gets obsolete and there is constant change of milestones and perceptions. The main goal of education, according to Sergei Kapitsa, is to prepare people for this change of knowledge, not for its abundance [2].

When offering additional education programmes we should teach the student to acquire knowledge, to be able to cognize, to learn. Lev Lourie, the founder of Saint-Petersburg Classical Gymnasium, stresses that the essence of the system of the classical gymnasium, a German invention, lies in that they make a person work for a certain period of time within certain special fields of activity. As a rule these are very strong mathematics, two ancient languages, and two modern ones, the rest being not that important. Passing all of this takes hard study. This is why it absolutely doesn't matter whether to teach children Latin or Greek or give them an overdose of mathematics. Roughly speaking, if you want to execute some job with a start and an end, this would be the most correct approach. Also it teaches the notion that there are no insurmountable tasks. Today you design a law, tomorrow you create a club, the next day you write a book. Each task has its solution algorithm [2].

The concept of additional engineering education is being implemented in many universities of the world: Massachusetts Institute of Technology (USA), University of Toronto (Canada), University of New South Wales (Australia), Nanyang Polytechnic (Singapore), and others, as well as in Russian ones, for example, Siberian Federal University, Omsk State Technical University, Ural State University of Railway Transport, and Volga State University of Technology. Analysis of their programmes shows that Russian HEIs focus on added fundamental training in students' professional area: natural sciences, mathematics, and technology, while other universities, especially the American ones, also include training in humanities and development of universal (personal) skills aimed at satisfying such prospective requirements of the society, as innovation, enterprise, and leadership [3].

A particular example of a programme close in content and ideological concept to EEEP TPU is the Gordon-MIT Engineering Leadership Program suggested by Bernard M. Gordon [4]. Gordon believed that elite education programmes of this kind will inspire young people to become engineers capable of working with various types of resources: financial, personal, and material, on all levels of engineering activities [4].

This way, the importance of developing elite engineering education programmes is, of course, one of the most topical and timely objectives. In order to achieve this set goal it is necessary to fulfill the following tasks:

1. Develop the concept of the EEEP.
2. Create a system of selecting talented students for training within the EEEP.
3. Develop a system of selecting talented teachers that would provide teaching to EEEP students.

4. Create a training programme for students that would condition them to form the personal and interdisciplinary competencies of using their knowledge in practice, which would allow them to solve engineering and entrepreneurial tasks.

Let us consider each of the tasks and the possible ways to solve them in more detail.

II. EEEP CONCEPT

The goal of the elite engineering education system is to train professionals of an absolutely new level that are capable of making a complex combination of research, project, and entrepreneurial activities, possess deep fundamental knowledge, have a good grip of engineering creativity, and are able to work in a team.

The concept of Elite Engineering Education is based on the requirements set by the GEP Standard of TPU, as well as the best experience and practices of implementing the CDIO concept, focusing on fundamentality, professionalism, innovation, enterprise, and leadership [3].

The EEEP is implemented in parallel with training in a basic chosen major during the entire duration of study.

During the training process a student must acquire:

1. In-depth knowledge of fundamental sciences (mathematics, physics, economics).
2. Profound professional competencies
3. Competencies in the area of engineering entrepreneurship that include project work, engineering invention, innovation theory, and market knowledge.
4. Fluency in English language.
5. Leadership and teamwork skills through forming a learner-centered educational environment in the process of training.
6. A holistic worldview and form a complex value thinking [3].

At the end of training within the EEEP students are awarded a Certificate indicating the number of hours and the list of disciplines studied during this training.

III. STUDENT SELECTION SYSTEM

Many aspects of student selection, as well as expected graduation and drop-out rates, are based on the normal distribution law (Gaussian distribution), according to which the characteristics of living and non-living matter are distributed in our world. The Gaussian curve shows that the percentage of gifted people, as well as that of absolutely untalented ones, is 3-5%, which is further supported by a research showing that approximately 5% of people reach the IQ value of 130 [5].

Since young people entering universities are yet unformed personalities, it is logical to enroll 10% of promising students that have passed their entrance exams.

The task of creating a system for selecting students for training within the EEEP includes the following subtasks:

a) creation and regular updating of a test activity database;

At the age of 17-18 (regular university entrance age in Russia) a human's intellectual sphere continues to develop and improve, and often it is hard or even impossible to clearly identify the students that are potentially capable of digesting knowledge, and those that are unfit. This is why test activities identify the existing image of a student's intellectual load and minimal intellectual skills. The selection tests offered to students contain tasks that allow evaluating their knowledge levels in physics and mathematics, logical thinking, general awareness, and their skills of transferring theory to practice.

In TPU such base was refreshed by 7% per year. Since 2004 (introduction of the EEEP system in TPU) a very large volume of tests has been accumulated, and a software application was created on their basis. The Education Quality Assurance Center of TPU is responsible for carrying out the testing and developing new test materials.

b) selecting students for training;

Applicants are selected on a competitive basis from among the students of all engineering majors entering their first year of studies. Competitive selection allows forming additional motivation and inspires students to overcome difficulties. The competition is performed in two stages:

1. The first stage involves a preliminary selection of candidates based on the results of entry examination. It results into forming a list of candidates to be invited to the second stage.

2. The second stage of the competition is carried out in the form of testing that includes elements identifying the contestants' creative potential. Basing on this stage's findings, new lists are formed containing those students who are recommended for continuing their training within the EEEP system.

In 2012 more than 1200 students took part in the first stage of the competition, 700 of which were recommended for participation in the second stage with 228 passing it. Significant attrition occurs after enrolling in the programme [3].

c) forming students' motivation system;

A system for motivating students for academic activities is necessary, because it is imperative to demonstrate the reason for studying additional disciplines to talented young people. The EEEP in TPU includes two components: material and non-material motivation.

Material motivation is recorded and established in the Statement of EEEP in TPU. It includes:

- monthly bonus the amount of 70 % and 140 % of standard scholarship for B- and A-grade students respectively;
- the opportunity to extend the examination period by two weeks from the beginning of an academic year;

- the opportunity to participate in a summer school free of charge.

We consider it important to continue the development of material motivation. It is suggested to offer EEEP students additional credit points on admission to the dormitory, and a corrective coefficient to grade point average for participation in any competition or job allocation (at least 1.1 or 1.2).

While forming the system of non-material motivation for students, consideration was given to students' age specifics and their value system. This is why the EEEP students' training starts with communicative training sessions that allow them to satisfy their communication need, create a reference group, and find their place within the collective. The recognition need is satisfied by means of availability of own room (computer class) for study, relaxation, and communication with friends; and the fact that classes for the EEEP students are conducted by best teachers. The self-improvement need is satisfied with the curriculum that includes many interesting blocks not available in the standard curricula: theory of inventive problem solving (TRIZ), games of intellect, introduction to project activities and engineering invention; teamwork on problem-oriented projects; careful work with student initiative: EEEP website, traditional May and September outdoor meetings.

d) development of an algorithm for forming the individual learning pathway of an EEEP student within the learner-centered environment.

Formation of a student's individual learning pathway starts with an individual psychologist advice based on social psychological diagnostics. This diagnostics includes the following tests: LSC (level of subjective control), style of thinking, social type, WAM (well-being, activity, mood), and resilience test.

This set of tests helps to identify a student's personal inclinations within the bounds of one of the three future pathways:

1. research, working in higher education;
2. industrial activity, managerial positions included;
3. own business, including the use of knowledge-intensive technologies.

Regardless of the fact that a given pathway may change during the training process, a student starts to form an image of the future, which is connected with the need to master the EEEP.

On one's second year a student chooses a task-oriented project that can be carried out at any of TPU's engineering departments. This sometimes leads to changing the previously chosen profession.

On one's middle and senior years an EEEP student forms one's pathway more clearly through acquiring additional opportunities (student exchange, internships, seminars, training sessions).

If help is necessary to make a decision, a student addresses the psychologist that coaches the student during the entire period of one's EEEP training.

IV. TEACHER SELECTION SYSTEM

The system of selecting teachers to carry out the training process includes:

- a) selection of teaching staff capable of creating programmes of the required level and updating them regularly by increasing their own qualification. Invitation of the leading teachers from Tomsk, rest of Russia, and abroad to teach in the EEEP;
- b) unique teacher retraining programmes;
- c) feedback system based on the results of every semester (student surveys, development of teacher assessment system etc.);
- d) development of a system for forming teaching staff reserves.

In order to actualize these tasks the following actions should be taken:

Step 1. Define the range of competencies of an EEEP student and raise the corresponding requirements to programmes of both fundamental and professional cycle.

Step 2. Announce a competition for development of special programmes for the EEEP system.

Step 3. Announce a competition among teachers that provide training for EEEP students.

Step 4. Obtain the necessary administrative and financial resources to additionally reward the teachers working with EEEP students and the panel of experts selecting these programmes.

Step 5. Introduce regular seminars on elite education methodology for the teachers working with EEEP students.

To perform the c) task it is necessary to create a system for assessing the quality of teaching any given discipline and tabulate results at the end of each cycle.

At the present moment, EEEP possesses a system of teacher competence assessment by students at the end of each semester. Questionnaires are filled anonymously, their combined results allowing to identify the best teachers and deficiencies of this or that competence within the rest. This data is passed to heads of their departments who make subsequent administrative decisions.

V. EEE STUDENT TRAINING PROGRAMME

As was mentioned above, it is necessary to create the EEEP student training programme conditioning the formation of students' personal and interdisciplinary competencies of using their knowledge in practice, which would allow them to solve engineering and entrepreneurial tasks.

Training within the EEEP is divided into three stages.

Stage I. Fundamentals training (1st and 2nd years) providing in-depth training in the disciplines of "Advanced mathematics", "Physics", and "Economics" for separate inter-institute joint academic groups. A number of psychological and

educational programmes are realized, aimed at the formation and development of the necessary personal qualities.

Stage II. Professional training in innovative, inventive, and entrepreneurial activities (3rd and 4th years) involving in-depth training in general professional disciplines, special disciplines, and economical disciplines. The stage includes carrying out group-based problem-oriented projects jointly with the teachers from departments of allied specializations, specialists from manufacturing companies, research and development institutes, and institutes of Russian Academy of Sciences.

The professional cycle can be subdivided into 3 main training directions:

1. Engineering leadership
2. Design and innovation
3. Project design and management

The choice of content for this stage is upheld by the results of a research by MIT that highlights these skills and competencies as the most important and demanded in "real life" conditions after graduation [6].

Stage III. Special training (5th-6th years). Training is performed according to an individual plan prepared by the student's major department and the client that generally is the student's future employer.

The Table below presents an overview of the curriculum currently provided to EEEP students in TPU in addition to their basic training.

TABLE I. EEEP STUDENT CURRICULUM

Year	Semester	Fundamental cycle	Professional cycle	Language training	Project work	Conference participation
First	1st	Mathematics/Physics	«Engineering leadership»: Applied psychology for students	English language		
	2nd		«Engineering leadership»: Introduction to engineering invention «Design and innovation»: Introduction to project activities			
Summer				Summer school		

Year	Semester	Fundamental cycle	Professional cycle	Language training	Project work	Conference participation	
Second	3rd	Mathematics/Physics		Winter school			
	4th	Mathematics					
Third	5th	Economics	« Engineering leadership »: Theory of inventive problem solving (TRIZ)	Advanced English	Task-oriented project		
	6th		« Design and innovation »: Computer-aided methods of mathematical and physical problem-solving « Project design and management »: Engineering enterprise			All-university conference of EEEP students (I)	
Fourth	7th		« Project design and management »: Project management				
	8th		« Design and innovation »: Synergetics for engineers Innovation management				All-university conference of EEEP students (II)

It should be noted that professional cycle also includes elective subjects that are:

1. Fundraising
2. Technologies
3. Instrumental block
4. Global vision
5. Subjects included in the individual study plan for the purposes of work on the individual task-oriented project.

VI. CONCLUSION

Each year around 200 students are selected for training in the EEEP, which is approximately 10% of the first-year engineering students funded by the State. Nearly half of these stay for their third year, while only a quarter make it to the fifth. During the time of existence of the EEEP system in TPU over 1600 students were enrolled in the programme with only 253 fully mastering it. This high attrition rate is conditioned by the high requirements to participants of the programme and its

difficulty level that are within the power of only the most motivated and strong-willed students [3].

In order to understand the actual quality of such education's outcomes a research was carried out comparing 1st year EEEP students, 4th year EEEP students, and "ordinary" GEP students in their 5th and 6th years of study according to their "Entrepreneur profile" encompassing such qualities as ambition, readiness to take risks, fast decision-making, ability to attract people, stress resistance, perseverance, customer focus, and others. Out of 15 criteria total, EEEP 4th years have surpassed their 5-6th year GEP counterparts in 12. As a matter of fact, even the EEEP freshmen have managed to outrun the GEP seniors in 5 criteria and roughly match them in 3 more, which is a truly inspiring finding.

Another indication of quality is the fact that all of the EEEP master's programme graduates have been employed by leading industrial companies and research centers with prospects for quick career advancement according to their readiness for enterprise and innovation, or have created their own small businesses to carry on with the developments they have started in the university [3].

Combined with the numbers of students entering, dropping out of, and graduating from the EEEP, these quality indicators confirm the correctness of the chosen student selection and training approaches.

Presently, TPU consistently occupies the leading positions in Russian engineering HEI rankings, creating itself a very positive image that conditions high inflow of students both from Russia and other countries. Together with TPU's active involvement in cooperation with foreign partners and availability of the Elite Engineering Education Programme, this allows to effectively attract, identify, and train talented students, shaping them into highly qualified professionals that would define the future of engineering.

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