KURUSHINA, V.A., KURUSHINA, E.V. and ZEMENKOVA, M.Y. 2018. Technologies of polytechnic education in global benchmark higher education institutions. *IOP conference series: materials science and engineering* [online], 357: proceedings of the International conference on transport and storage of hydrocarbons, 10-12 January 2018, Tyumen, Russia, article number 012028. Available from: https://doi.org/10.1088/1757-899X/357/1/012028

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2018

IOP Conf. Series: Materials Science and Engineering **357** (2018) 012028 doi:10.1088/1757-899X/357/1/012028

Technologies of polytechnic education in global benchmark higher education institutions

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Abstract. The Russian polytechnic education is going through the sequence of transformations started with introduction of bachelor and master degrees in the higher education instead of the previous "specialists". The next stage of reformation in the Russian polytechnic education should imply the growth in quality of teaching and learning experience that is possible to achieve by accumulating the best education practices of the world-class universities using the benchmarking method. This paper gives an overview of some major distinctive features of the foreign benchmark higher education institution and the Russian university of polytechnic profile. The parameters that allowed the authors to select the foreign institution for comparison include the scope of educational profile, industrial specialization, connections with the leading regional corporations, size of the city and number of students. When considering the possibilities of using relevant higher education practices of the world level, the authors emphasize the importance of formation of a new mentality of an engineer, the role of computer technologies in engineering education, the provision of licensed software for the educational process which exceeds the level of a regional Russian university, and successful staff technologies (e.g., inviting "guest" lecturers or having 2-3 lecturers per course).

1. Introduction

Reforms in the Russian education led to the formation of a pool of federal and research universities from among the best Russian universities. Prospects for the development of higher education in the regions are connected with the possibility of forming benchmark universities. The Expert Council of the Ministry of Education and Science of the Russian Federation identified the list of regional universities, on the basis of which benchmark universities will be established. Growth of the management efficiency of the preparation of engineers is one of the basic conditions of modernization of the Russian economy [1]. The Russian university selected for this study is a regional university of engineering profile in a medium-size city of Russia and the students' center of the region. The main task of this Russian university is reforming the existing system of engineering education in order to provide the region with engineering personnel with the skills to conduct the next industrial revolution. The best foreign practices in the field of higher education should be studied in order to form the development program for the Russian university. In the present research, the differences in education technologies are investigated as a comparison between the current characteristics of engineering education in the Russian university and the technical university of the world level, chosen according to the criteria listed in Section 2.

The aim of this paper is to identify the main differences between the engineering higher education in the world-class university and in one of the engineering universities in Russia in order to determine

what kind of qualitative changes in the education process the Russian university can benefit from in the possible future.

The paper is structured as follows. General introduction to this research is given in Section 1. Section 2 provides the characteristics of the research method and the details of choice of the foreign benchmark university. In Section 3, four major differences between the analyzed Russian and foreign engineering education are considered: course contents and software, information resources, staff solutions, and quality control means. The main outcomes of this paper are given in Section 4.

2. Research method

Benchmarking is selected for this study as the method of objective systematic comparison. As noted by O.V. Lenkova [2], introduction of benchmarking as an independent management tool is related to the Strategic Planning Institute in Cambridge (USA). In this institute, it was found in 1972 that the knowledge of the best experience of other organizations, which are successful in the similar conditions, allows one to take effective decisions in the field of competition. G. Watson, the past leader of the American Society for Quality (ASQ), considers benchmarking as a systematic and continuous measurement process: assessment of processes of the enterprise and comparison with the processes of the world-leading enterprises to collect information which will help the organization to take action to improve its' performance [3]. According to Y. Ohinata [4], the process of adopting the method should be preceded by the procedures of comparison and identification of weaknesses of the organization.

Within the framework of this study, when selecting benchmark universities, the industrial profile of higher education institutions and its' connection with solving the regional tasks was in priority. The selection was performed taking into account that the university should be located in the medium-size city and constitute a major student center, but not the main city of the state. At the university acting as a benchmark, schools of geology and engineering should exist; the number of university students has to be comparable to the number of students in the Russian university (about 15 thousand people). The university should train the future staff for large corporations in the region, including oil and gas industry.

Considering these criteria and the list of universities with diplomas recognized in the Russian Federation [5], the authors selected one of the universities of the world level as a benchmark (which will be referred as the benchmark university or reference university further). Some attractive characteristics of this university for the Russian university are:

- position in the international rankings of THE and QS (should be in the top 200 universities);
- high proportion of masters and post-graduate students (over 25% of the number of students);
- high percentage of foreign students (over 30%);
- compliance of university research activities with international quality standards;
- university employees awarded with Nobel Prize.

Two universities are compared with each other in this paper in the following key aspects: content of courses which are not present in the Russian university; dominating mindset of lecturers and students and related use of resources; personnel for course teaching; and ways to control the education result. The authors attempt to define the ways for improvement for the Russian university in each considered aspect.

3. Comparison results

3.1. Structure of educational programs in the benchmark university

Comparison of educational technologies in the selected reference university and the Russian university allowed identifying advantages of the reference university related to the structure of programs in engineering and to the degree of informatization of the subjects. Specifically, the course of engineering mathematics is followed by the course of design with computational and programming skills. An example of such course may include 6 weeks of programming in Matlab, 3 weeks of tasks performed in Solidworks and 1 week of exercises in SprutCam. A design assignment with an open end

to complete in 2-3 weeks is also normally included in such course. This subject may be given to the second year students of different specialties, for example, mechanical and civil engineering students.

As for example given above, the Solidworks software allows designing two- and three-dimensional solid bodies separately and in assembly, and also liquids in a closed volume, with the further modeling of loads and deformations. Students' designs from Solidworks are loaded into the SprutCam software where the user selects a machine for the production of parts from the workpiece, sets the operations and location of the tool to obtain the object of the desired size and shape. Students have the opportunity to see the work of the machine in the laboratory in accordance with the previously created operations in SprutCam. The programs like Solidworks, Abaqus and Ansys can be involved for design exercises at different levels of education, from the first attempts made by undergraduate students to the research by PhD students.

The Matlab software is applied in many general and specialized disciplines in the benchmark university. For example, one of the specialized courses of the third year at the reference university first involves solving problems without information technology, by hand and a calculator, and then solving problems in the Matlab environment using the functions of integrating differential equations and all the studied lectures’ material.

Thus, an undergraduate student of the university, chosen as a benchmark, finishes studies familiar with the various software, basics of programming and three-dimensional modeling. In comparison with the Russian university, the students have stronger adaptive qualities for the world of computerized technology. The connection of the mathematics course through the calculation and programming course to the specialized courses is often missing in the Russian education for the majority of engineers. The Russian specialties imply either a pure engineering, practice-related education, or a mathematical and programming education, but not a combination of them. Since the advanced engineering idea now speaks English and the coding language, the task of transformation for the Russian university is to break this linguistic barrier before the resources of a new knowledge for engineering students.

3.2. Formation of a new mentality of an engineer in the era of information technologies

The modern engineer exists in the time of the fifth technological order, lives in the conditions of strengthening globalization processes in the economy [6, 7] and migration of the population, availability of the Internet with access to the continuously updated information and the best practices from all over the world. In these conditions, former priorities of mentality of engineers should be left in the past along with the aging generation of technology. The mentality of an engineer of the new generation assumes: 1) flexibility of mind; 2) high susceptibility and desire for a new knowledge; 3) ability to abandon previous ideas and experiences, which do not work anymore; 4) knowledge of foreign languages and programming; 5) communication skills and ability to work in a team to achieve a common goal.

Reforms of polytechnic education should begin, firstly, with an increase in the level of information culture, since Russia is behind the developed countries in the transition to the fifth technological order. It is largely due to the inadequate formation of its core, including computer equipment, software and information services [8]. The university chosen as a benchmark annually spends more than 3.5 million dollars for the work of the library, of which around 400 thousand dollars is spent on access to databases of the latest scientific papers and books. The university owns software licenses sufficient to cover the students working in the classroom at the same time, for example, 100 licenses per program, or it is available for all the students without limitation.

In the Russian university, the information resources appear more limited, but there is also a related problem. The students are supposed to follow the course instructions, including the list of resources, which students should use to obtain the correct answers. Thus, the education becomes largely the knowledge transfer from the lecturer to students, where the primary goal is to avoid the information loss. The initiative of students to suggest the alternative solutions often is not appreciated. This

problem is not just something typical for one lecturer, one university, or one country, it is a general phenomenon known as the fixed mindset in education [9].

The benchmark university selected for the current comparison, on the contrary, puts the main focus on the students’ self-study, encourages students to look for their own answers, create their own solutions, and discussions with the lecturer about the material are appreciated. Real case studies are often given as design assignments, where it is possible to discover many answers and to progress from a simple to a complex solution. This way of teaching and learning requires a continuous effort from all the participants of the process and leads to the shift from thinking about the result of teaching as a well-known, clear outcome to the continuously improving outcome.

One of the related advantages of the studied benchmark university is that each year the course and its assignments are reviewed and updated by the lecturers. This is partially the result of the updated requirements of the accreditation procedure, but also the result of responding to the students’ feedback. The feedback in the reference university is collected in the middle of the term to reveal the problems during teaching the course, and also at the end of term to allow the lecturer make changes for the next year. At the same time, the feedback of students in the Russian university is rarely applied as an instrument of improvement for the ongoing teaching.

3.3. Strategy of formation of the teaching staff and education technologies in the benchmark university

The next important component of reforming the polytechnic education is a successful staff strategy that ensures the achievement of the goals stipulated by the Bologna process: transparency, quality, growth, efficiency and skill [10]. To provide the high-quality education, the benchmark university uses a modular system and technology of inviting "guests" – specialists from companies, competent in certain topics. Companies send their employees to demonstrate the professional level of knowing and applying the material required for work in the form of 1-2 hour classes at the university. For example, every second or third lecture of the course of offshore extracting facilities for master's students of the second year of study is held by "guests" from companies.

In addition, the course lectures and practical classes are not given all by the same teacher. There is a coordinator at the head of the course – usually the main lecturer, who selects 1-2 more lecturers and the necessary number of demonstrators for the course and links the theoretical blocks and practical assignments with each other. Demonstrators are invited personnel from post-graduate students or even undergraduate students of the fourth year of studies competent in demonstrating certain software or in solving problems for practical classes. Recruiting the additional junior staff to conduct classes at the bachelor's level is the distinctive feature of the benchmark university.

The supporting staff in the practical class has the following functions: answers students' questions on solving problems; solves problems that arise during the class; by all means creates a favorable, safe environment for effective teaching. Demonstrators are “good” when they can explain and show the solution of the problem in different ways (so that students understand it), and also provide the necessary connection with the lecture material. Requirements for demonstrators include: 1) a complete bachelor's degree (or a candidate needs to be a fourth-year student) in the study area; 2) an expert level in the subject; 3) an understanding of what knowledge and skills a student should have at the end of the course; 4) experience in demonstrations (appreciated).

Favorable environment in the classroom includes both physical (lighting, ventilation, room temperature), and psychological and social factors. Particular attention in the benchmark university is paid to creating equal opportunities for students. The course lecturer is obliged to provide students with the material in various forms: books, articles, audio recordings, presentations, etc. For health reasons, students are provided with separate rooms for each examination. At the level of demonstrator, during practical classes, it is necessary not to prioritize when communicating with students from different countries, of different age, gender, religion, orientation, etc.

The qualification of lecturers in the field of higher education in the country of the benchmark university is regulated using system of five spheres of competence. The basic principles of this system

are the accessibility of education for all and the depth of knowledge of the subject. One of the most important areas is the design of the learning environment, which includes all the teaching means (simulators, computers, programs, lectures, etc.), as well as the limitless support from demonstrators and lecturers.

The goal of the benchmark university is to provide not just “good” education, but "excellent" education. A prerequisite for the high-quality education is the effective feedback so that the student can independently regulate the learning process. In the reference university, the lecturers aim to follow the feedback principles, as formulated in [11]. According to them, the lecturer “helps to clarify what good performance is (goals, criteria, expected standards); facilitates the development of self-assessment (reflection) in learning; provides high-quality information to students about their training; encourages teacher and peer dialogue around learning; encourages positive motivational beliefs and self-esteem; provides opportunities to close the gap between the current and desired performance; provides information to teachers that can be used to help shape teaching” [11].

If students do not share (at least partially) the concepts of their lecturer with respect to evaluation objectives (as well as criteria and standards), then the feedback information they receive is unlikely to lead to the desired result, as noted in [12]. In this case, it will be difficult for students to estimate the discrepancy between the required and the actual level of performance. It is also important to note that feedback not only leads the students towards academic goals, but, over time, it will also play a role in clarifying the goals themselves [13].

3.4. Quality control of teaching

All the educational programs in the reference university are accredited through the bodies, specialized for different kinds of engineering: chemical engineering, mechanical engineering, civil engineering, etc. These institutions obtain the licenses to accredit the educational programs and update their requirements for universities regularly. At the same time, the Russian educational programs for bachelors and masters are currently regulated by one body – the Ministry of Education and Science.

Quality control of education at the benchmark university is provided by: 1) the duration of tests (the exam lasts 2-4 hours); 2) recruiting staff not associated with the course to control the examination process (invigilators); 3) the anonymity of works submitted for evaluation; 4) showing test results in the electronic system.

Examination of students in the reference university is performed in the written form only. The examination assignments pass the double check after they are created by the lecturer: the internal check with the other lecturer in the same university, and the external check with the lecturer from a different university. The examinations are held in the fall and spring session time and provide the main contribution to the students’ marks.

In the Russian university, there is the system of three attestations for students per term, including the final test, and the students’ marks are given as results of tests in the electronic system, or written tests, or oral examination. Additional examinations are held after the end of term for students who did not pass the regular tests during the term successfully. The examinations are normally conducted by the same lecturer who taught the subject, and the contents of tests are not checked with other lecturers. However, there is the system of external and independent control of students’ knowledge in Russia – FEPO, which implies that selected groups of students in university can be tested for the knowledge of particular subjects during the term.

The authors of this study suggest that the practice of recruited independent personnel (invigilators) to conduct written examinations in the reference university is the most perspective to improve the examination process in Russia.

4. Conclusions

The differences examined in this paper between the Russian and the foreign practices of engineering education are given in Table 1. It is worth noting that the actual differences are not limited to this list, and if other universities are selected for comparison, the results may differ. The described distinctions

can serve as the guidelines for qualitative changes in the Russian education in general and in certain higher education institutions in particular.

Table 1. Comparative analysis of characteristics of the process of engineering education in two universities

Characteristics	Reference university	Russian university
1. Provision of licensed software for students	Software is provided for all the students to meet all their needs expected while they study towards the degree.	Very basic resources like MS Office are provided. Students are encouraged to take software courses, which can be beneficial for final thesis and future career, on their own outside of university.
2. Access to scientific papers	Access is provided for all the students to databases like sciencedirect.com, onepetro.org, etc., where it is possible to find the latest papers published in the leading journals of the field throughout the world.	Students can access the papers from the free system of the Russian citation index elibrary.ru.
3. Courses of computations and programming	Necessary part of engineering education providing the link between engineering mathematics and specialized disciplines, and also providing the possible basis for the final year thesis.	There is a course of general informatics, including some programming tasks, which is not related to mathematics course or specialized courses.
4. Tutorials and practical hours of specialized courses	Exercises are solved by hand on tutorials, and then similar tasks can be solved in code or in specialized software.	Most of exercises are solved by hand with scientific calculator, or in Excel.
5. Course staff	Course coordinator, 1-3 lecturers on the course, guest lecturers, demonstrators. The course is created or modified according to feedback from the previous year by a team of teachers.	In majority of cases, 1 lecturer and, possibly, but not necessarily, 1-3 demonstrators are assigned to the course. All decisions on tasks and forms of teaching are responsibility of the single lecturer.
6. Feedback from students	Feedback is collected regularly in multiple ways, including the written feedback in the middle and in the end of course, but not limited to it.	Feedback is collected occasionally, depending on the course lecturer.
7. Examination	Conducted by the personnel which was not involved in teaching the subject.	Conducted by the staff teaching the course.
8. Growth, initiative, creativity in students learning	Exercises with multiple solutions or open end, and design exercises based on real cases are the necessary part of learning. Students are encouraged to use any information resources they can find, develop new skills and their own ways to solve the tasks. Discussions with lecturers, demonstrators and among the students on the subject are strongly encouraged.	Students are supposed to follow the course instructions and instructions for the particular task in order to obtain the defined answer. Students may apply information from not listed sources if it leads to the same final answer. Discussions can be a part of the education process, but not widely encouraged.

As the result of this study, adoption of the best teaching practices to educate engineers in Russia can take the form of: changes in the structure of educational programs; increased spending for information technologies; increase in the number of tasks with multiple solutions and open end; encouraging discussions in the classroom; increase in the number of lecturers per subject; improving teaching based on the students' feedback; shifting the focus from the knowledge transfer to growing students' skills of self-education. It can become one of the steps for reducing the delay in science and technology observed in Russia. A modern engineer has to change along with evolutionary changes in technology and learn continuously. The task of a benchmark university is to provide its graduates with these advantages.

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