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# Industrialization as a major driver of engineering education transformation. Engineering education: a course for new industrialization

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**The article deals with key mechanisms of native engineering training system modernization in the context of new industrialization course declared by the Russian Government and main tendencies of modern native and world engineering education development.**

***Key words:*** *new industrialization, engineering education, professional skills of engineers, globalization of higher education, transdisciplinary university of XXI century.*

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Making report at the beginning of the autumn of 2011 in Cherepovets Vladimir Putin told about his visit to one of near-Moscow schools where he read the statement in a social science textbook about the fact that in the 21-st century in comparison with the previous one "the center stage is taken by the service sphere, but production sphere is yielding to it".

"It is a very controversial point, very controversial. Now we can see that some countries, which have got carried away for deindustrialization, are reaping hard, bitter fruits. Following the production they are losing engineering centers, brains are draining, and this makes the condition for degradation. Therefore, it is too early to speak that industrialization has died. We need industrialization on a new base. It is true", – the Chairman of the Government commented the statement [1].

At the end of 2011 at meeting of All-Russia public organization "Business Russia", a candidate for President of the country Vladimir Putin lifted the veil over the new industrialization project advertised by him before [2]. According to his version, to change the structure of economy one needs to modernize or organize some million of high-tech working places.

In April 2012 the elected President being in the position of the Chairman of the Government reported to the State Duma about his work. Presenting the plans for the future he stated the development of modern components of production process as a strategic task for the nearest years noticing that the world has entered the epoch of turbulence and a new wave of technological changes is coming [3].

7, May, 2012 being already President of Russia Vladimir Putin signed 13 Decrees including the decree setting a new industrial project – creation of 25 million of modern high-tech working places by 2020.

This industrial project will become the third one in the history of our country.

The first "empire" industrialization was started by introducing the policy of protectionism in 1822. Due to high custom tariffs and defense of internal market from foreign competition in the Russian empire the competitive cotton, textile and sugar manufacturing industries were established. Machinery production appeared. A serious engineering reconstruction of metallurgy was performed. The railway boom took place.

The second "social" industrialization started after the adoption of the first five-year plan of national economy development at the XV Congress of All-Union Communist Party (of Bolsheviks). By the end of the second five-year period the Soviet Union took the second place in the volume of industrial

production in the world yielding only to the USA. In the 1930's the growth of industrial production amounted in average 15-18 % per year. The accelerated industrialization permitted the USSR to achieve economic independence from the West in the strategic production. Within the period of two five-year periods, new fields of industry were created: building, aviation, automobile, tractor-manufacturing, chemical etc.

Both industrial waves were accompanied by drastic reforming in the native system of engineering education [4, 5, 6].

In Russia higher engineering education itself appeared almost simultaneously with the first industrial breakthrough. In 1810 the school of engineering corporals (busmen) training was reorganized in engineering college with two departments. Busmen department offered three-year-course for training junior officers of engineering corps, engineering department offered two-year-course for officers of engineering profile. The best graduates of Busmen Department were enrolled in Officer Department. After introduction of additional training stage in the Engineering college that was named Main Engineering College the systematic approach to establishment of Russian higher engineering school appropriate for current challenges was formed.

The network of schools was gradually extended: in 1828 the Technological Institute was established, in 1830 — Architectural College, and in 1832 — College of Civil Engineers. Besides, technological institutes were established in Kharkov and Riga, as well as Imperial Engineering College (now – MSTU named after N.E. Bauman). In 1900 at the end of the 19-th century Tomsk Technological Institute of Emperor Nikolay II was established, a first native engineering university on the vast territory of the Asian part of Russia.

Finish of building Transsibir trunk line provoked rapid growth of economic development in Siberia. The new industrial development vector required greater number of engineers. That is why old engineering institutions extended as quickly as possible, but it was not enough, therefore new ones were established. New institutions were of polytechnic type and had a four-year curriculum. Large polytechnic institutes were established in Kiev and Warsaw, Sankt-Petersburg and Novocherkassk.

Engineer's job was gradually becoming very popular and the number of young men wishing to get it was several times more than the number of vacancies. In 1913 the average income of industrial engineer was 10 times more than the average salary of a low-qualified worker and 2-3 times – that of qualified one (a turner, a fitter, a master etc.). The majority of engineering institutions applied competitive entrance examination for students' selection. The prestige of a professor in engineering institutions was very high and best talented men competed for the right to occupy the vacant positions in teaching staff.

In the period of Nikolay's II rule there appeared some new challenges. Now engineering specialists were in demand by not only state organizations and institutions but also large and small business enterprises of the developing industries (electrical engineering, oil refining and chemical industry, machinery, metal and wood industry, raw materials, etc.), as well as autonomous bodies. Therefore, the Tsar government paid special attention to extending and enhancing the quality of engineering education at the turn of the 19-20-th century. It appeared to be forward-looking enough to estimate the current perspectives of global scientific-engineering development in time and take measures, without which our country would not stand neither in the First nor in the Second World Wars and keep its status of the world power gained in the 19-th century. The public position of the Russian engineering institutes being under the personal auspice of emperors and highest officials was unique in Europe. According to P.N. Ignatiev's evidence, a Minister of Education, Nikolay II paid greater attention to the development of just engineering education and some institutions (first of all, Warsaw and Tomsk Technological Institutes) were under his personal auspice. Undoubtedly, this circumstance is one of the reasons for fantastic economic and infrastructure leap forward at the turn of the centuries. As a result, by the beginning of the First World War the Russian system of higher engineering education could be compared with leading European systems in relative scales (with respect to the number of population).

The research of recent years has shown that the basis for success of such native high-tech industries as power en-

gineering, machinery, chemical, electrical engineering, optical, aviation, ship-building, defense industries were founded not after the Revolution, but in the last two pre-revolutionary decades [5]. The USSR inherited from the Russian Empire strong and balanced, well funded system of engineering education.

Developing the Russian engineering education and science Peter I laid the foundation in the form of classical triad "gymnasium – academic university – scientific academy", which is based on the principle of governmental support under the condition of applied use. That principle remained unchangeable in the period of educational reforms of Ekaterina II and Alexander II as well as in the period of initial industrialization. It was not virtually changed even in the period of the social industrial breakthrough. In contrast to juridical and historical-philological, engineering education was preserved and continued to develop. After the ruin of the Tsar Empire it was successfully adopted to the needs of the Soviet planning economy through a number of reforms.

A new element in the educational system introduced by the Soviet power was the principle of egalitarian education, i.e. education for everybody that, in particular, meant enormous work in creation and enhancement of education and the system of research institutions in the regions, not only in the capitals.

Engineering in the USSR became more female. Soviet higher engineering institutions enrolled women without formal limitations and by the mid of the 50's of the 20-th century women made up one third of the engineering students, but among working engineers they amounted 28 %.

The Soviet achievement was increase in potential of the Academy of Science by means of establishment of research institutes as a first section of research organizational structure. In the period of Revolution all degrees were annihilated, but in 1930 they were restored (two degrees were approved: Candidate and Doctor of Science). Development of Soviet natural science and engineering can be characterized as a rise. The developed network of fundamental and applied branch research institutes, construction bureaus, and university laboratories covered the entire range of research. A lot of new technologies were designed. For example, only during the first five-year period the production of synthetic rubber, motorcycles, watches, cameras, excavators, high quality cement and steel was set up. On the developed industrial base it became possible to reweapon the army.

In the 30's the system of engineering education was forming and developing that permitted the USSR to come from the Agricultural Epoch to the Industrial one and became one of the leading countries in the world. Adoption of the first five-year plan and start of the second industrialization initiated the university reform of 1930, when in terms of the Decree of Supreme Council of National Economy of the USSR old institutes were disembodied, but on the basis of their departments, faculties and research schools numerous branch institutions were established that were under the authority of People's Commissariat for Economy and trained in large-scale narrow focused specialists in short-period curriculum. Thus, Tomsk Technological Institute by that time renamed in Siberian Technological Institute was divided into five institutes, three of which stayed in Tomsk (Siberian Mechanic-Machinery Institute, Siberian Chemical Engineering Institute and Tomsk Electromechanical Institute of Railway Engineers), Siberian Building Institute was moved to Novosibirsk, Siberian Metallurgical Institute – to Novokuznetsk.

The main task of the first five-year plan of higher and secondary education development was to increase specialists' graduation, first of all, in engineering speciaities, under the condition of their training quality improvement [7, 8]. The life of country economy according to five-year plans gave possibility to know the required number of engineers in every qualification beforehand. Under these circumstancese introduction of narrow specialization in engineers' training had definite advantages. For such a specialization institutes of polytechnic type were especially suitable, that served as a main reason for their division into separate institutes. Each of these institutes was established for training specialists in a definite branch of industry and, therefore, assigned to a definite governmental structure. Increase in the number of diploma engineers was achieved owing to "optimization" of the training process. Non-majors were taken

ENGINEERING EDUCATION 10'2012

away from the curricula, in some engineering universities the period of training was shortened to 3-4 years.

However, in the course of time the drawbacks of such training became obvious, and most of institutes, institutes with older traditions in particular, avoided narrow specialization and returned to curricula similar to those before the Revolution. The government offered People's Commissariats to review the list of qualifications which were trained in universities to reduce the list of specialities to the maximum and to approve them taking into account the development perspectives of the given economic branch and science and engineering achievements as well as the necessity to give a professional a wide general-science and general-engineering training for the profound acquirement of the speciality. Due to this Decree there was a wide discussion on the questions of profiles being arranged in the country. As a result instead of 950 specialities existed by the mid of 1935, only 275 wider specialities were included in the list.

In 1932 the Soviet of the People's Commissariats adopted a special Decree according to which the share of practical classes and production internship not less than 30-40 % of academic time are to be devoted in higher and secondary institutions of engineering profiles. For this purpose every engineering university was assigned to this or that enterprise, and students were obliged to submit individual reports on production internship, these reports were to be estimated at the examination.

The labor of university teachers was better stimulated, their salary increased. If in the 1920's a professor's salary amounted only 50 % of an industrial worker's salary, already in several years after launching the second industrial project, a professor's month salary was approximately ten times more than that of a worker. Extra pays were introduced again for scientific degrees and titles as well as the number of post-graduates increased (from one thousand in 1928 to 16,8 thous. – in 1940 and half of them was specialized in engineering fields). As a result, by the beginning of the War the native system of engineering education could train engineers ready for involvement in production process just after getting university diplomas.

Profession of an engineer became popular again and engineering institutions drew attention of the best pupils. The number of university students increased 2,8 times within the first five years. Particularly impressive was the growth of the number in engineering workers at machine-tool and metal-processing plants: from 28 th. in 1928 to 253 th. in 1937. Within the period from 1930 to the 1940's the number of engineering universities in the USSR increased 4 times and exceeded one and a half hundred. One can state that before the beginning of the Great Patriotic War the Soviet engineering school was formed and it was this fact that helped our country to rearrange economy for military needs quickly and then restore in the nearest year after the war in spite of all destructions.

At the same time, intensive socialist industrialization together with large-scale involvement in engineering education changed significantly the professional image. Liquidation of market economy and concentration of high-tech technologies in state enterprises exclusively resulted in regression of a number of engineering competencies (in particular, "economic" and "managerial"). In contrast to engineers of Tsar Russia characterized by great learning and good knowledge of European languages, Soviet engineers, as a rule, were narrow-focused specialists not almost speaking foreign languages. In the Post-Soviet period reduction in engineering competence range worsened even more. However, steady trend for engineering specialization, concentration of high-techs in large corporations, transformation of engineer into mass profession took place in the Western countries as well.

Industrialization and engineering education are interconnected processes. Industrial waves always revolutionize the system of engineering staff training. The first native industrialization formed a unique model of Russian engineering education and led to development of engineering institution network. As a result of the second "socialist" wave engineering profession became mass that, to tell the truth, resulted in some regular simplification and even dilution of engineering profession essence. In this period optimization of engineering university complex was carried out, the nomenclature of qualifications was put in

order; unification of training process was provided. Developed in the course of two industrial projects the system of Russian and then Soviet engineering education was efficient enough, that was demonstrated by widely recognized achievements of the USSR in science and engineering.

It is indicative that both industrial waves, Tsar and Soviet, had a number of common features:

- development of higher engineering institutions network quantitatively and qualitatively;
- increase in state investments into material base of engineering educational institutions multiply;
- active popularization of engineering and engineering staff training process;
- enrollment of the best school-leavers and raise of competition for engineering qualifications;
- growth of prestige and status of both engineer as a profession and a teacher in a higher engineering institution, simultaneous increase in their salary and wealth rate;
- sharp increase in the number of students in engineering universities, growth of post-graduates' and teachers' number;
- establishment of new qualifications and profiles in higher engineering education, putting in order the current nomenclature of specialities;
- raise in importance of research component of engineering staff training process, promotion of wide and general engineering training;
- actualization of production internship, direct contacts with economic production sector;
- high attention and interest to higher engineering institutions from the government.

But what conceptually new features should engineering education system gain for the third wave of industrialization?

The first new feature is interdisciplinary and transdisciplinary education accepted in Anglo-Saxon educational model according to which it is considered to be appropriate for a student to unite a course on material engineering and nuclear physics with evolutionary microbiology and marketing. In the leading foreign universities students' training and scientific research are, as a rule, performed in engineering, natural, social, humanitarian sciences and science about life (including medicine) taken together. Hence, interdisciplinarity, promoting today development of all breakthrough technologies, in foreign universities starts straight from student's years. Presumably, today we buy high-tech medical equipment mostly in the Western countries, because its development is started by the students – future doctors, engineers, physicists studying in the same university, living in the same hostel, spending time at the same parties.

Universities occupying steadily the leading positions in prestigious international ratings (ARWU, THE, QS World University Rankings, Webometrics,) – Cambridge, Harvard, Yale universities perform students' training in all basic profiles: social and humanitarian sciences, mathematics and natural sciences, medical and engineering sciences. Even Massachusetts Institute of Technology, the most prestigious engineering university in the world, has departments of biology, humanities, health protection, and management in its structures. Narrow "branch" specialization of the native universities resulting from socialist wave of industrialization, in the course of which appeared new industrial branches from the ground up is one of the key reasons for retardation of Russian higher educational institutions in both international ratings and in the volume and quality of scientific research.

Today in the world there is a tendency of gradual diffusion of boundaries among disciplines and qualifications, and every serious research makes a modern scientist use methods of "related disciplines" and place the object of research in other scientific dimension. Therefore, an engineer of new generation is to be a synthetic specialist as well. The fact is that in real life, especially in small high-tech companies that are the main generator of innovation in modern economy, an engineer turns out to be a researcher, an analyst, a consultant in a wide range of topics, and a manager simultaneously.

Quite recently, Yefim Pivovar, rector of Russian State Humanitarian University, a leading national humanitarian university, declared that there won't be "pure" humanitarians soon [8], as convergence among the sciences is of more significance. In this case

symbiosis of sciences is possible, quite different and far from each other. Association and enlargement of universities in Russia is necessary and inevitable, thinks Vladimir Vasiliev, rector of Saint-Petersburg National Research University of Information, Technologies, Mechanics and Optics. In his words, universities in, for example, Petersburg were established, basically, in the 1930's and were focused on one or another branch of industry and economy. Today the development of higher school is performed on the basis of definite interdisciplinary crossing that will intensify in time.

"Russia even delayed a little with the process of enlargement and association of universities, as this tendency has been obvious over the whole world long ago beginning from the USA and finishing with China", – noticed Vasiliev [9].

Andrey Fursenko, speaking at the Forum "Russia and the world: 2012-2020" [10], called not to oppose engineering and humanitarian education. In his opinion, in the sphere of education and science development it is necessary to transcend the technocratic scenario consistently, avoid branch division for knowledge convergence, as nowadays the most interesting researches are not divided in trends: for example, nano-bio-information-cognitive techniques are impossible to refer to natural or humanitarian sphere unambiguously. Skills in arguing, formulating one's thoughts beyond the common convictions are the main results of modern convergent education having interdisciplinary and super-disciplinary character, equally urgent for both future historian and future physicist.

Thus, we need "large" universities of new type. They are possible to be established in several ways. By means of uniting and enlargement as it was made in establishing most of federal universities or by arranging consortiums in which every university is legally independent. But for this purpose it is necessary to change the current legislation (curiously that a number of departments of MSU are legal units).

The bright example is Sorbonne that, in fact, gained its modern organization not as a result of mergering, but, vice verse, division [11].

In 1972 Sorbonne or University of Paris, after famous students' revolts of 1968, was divided into 13 autonomous universities, differentiating in profiles of training. Some of these universities are located in the historical buildings of Sorbonne, the rest – in other blocks of Paris and its suburbs.

At the same time all universities have a single infrastructure (for instance, Interuniversity library) and common administrative and academic units – Practical School of Higher Education, Paris University Office, and Academic University Administration. In addition, they are connected as a unified whole by a network of organizations and institutions of general assignment – such as Upgrading Professional Center, Occupational Guidance Center, Interuniversity Sport Center. Besides, each of these universities performs some function for common benefit. For example, at Descartes University there is interuniversity service of prophylactic medicine and health protection; at Paris-Sorbonne University there functions a Unified center of Documentation and Radio station; at New Sorbonne University – Culture center and Press-Agency.

New convergent universities are a necessary condition for interdisciplinarity. They give a student possibility to complete a course of system analysis at natural science department, a course of social engineering and resource efficiency at humanity department, engineering entrepreneurship – at economic department etc. in the process of study.

In fact, there is another way of interdisciplinary arrangement i.e. academic mobility, but domestic higher school is not ready for this in large-scale yet. Numerous administrative barriers, need in additional funds, underdeveloped transport infrastructure, price imbalance in rental property market – all these limits students' and teachers' mobility significantly. A European student can easily move from one country to another, without any loss, study there half of a year and get back. In our country it is often required to retake exams and re-credit when changing university, in this case universities can belong to different authorities that makes the procedure even more complicated.

One more new feature of Russian engineering education is connected with its inevitable globalization in both national and international aspect.

What is it conditioned by? Within the country – by the announced program of

organizing 25 (!) million of new high-tech working places. In the external aspect – by globalization of the world economy and WTO accession. External factor implies inevitable harmonization of the native engineering training model to the world best one.

What changes will it require? Significant.

In this case the role of school training system and unified state examination (USE) is to be reoriented, first of all, to the new wave of industrialization. Obligatory exams for all school leavers, apart from mathematics and Russian, are to be physics, chemistry, biology, social science and foreign language. It is a key problem forming the basis for algorithm of vocational training of new generation and requires an urgent solution. With present approach, when USE in physics is passed by only 25-30 % of school leavers and, doing so, competition in engineering profiles is potentially 3-4 times lower than in the other ones. To organize a new industrialization wave is hard, even under the condition that of "25 million" future university graduates will constitute only a part. The road to higher engineering education should be wider. However, taking into account all mentioned above, any routs are to lead a school leaver to a unified sub-disciplinary "Rome" all the same.

The additional mechanism, promoting the transition from accepted narrow-focused educational paradigm to convergent transdisciplinary university of the 21-st century, can be development of wide network of lyceums-boarding schools at leading universities of the country strictly regulated by federal and regional programs of youth support in Russia.

The necessary final condition for preparation of launch platform of the third Russian industrial wave is to become total striving of potential entrants to choose just engineering qualifications. How to do it? Inserting Russian higher educational institutions into the international system of curricula accreditation and professional engineers' certification.

Certified professional engineers entered in definite national registers are, in fact, engineering elite for industrial companies and state in general. It is they who drive economy in the way of innovations and provide its competitiveness. What does the presence of definite number of specialists of international level entered in corresponding registers get to a company? A possibility to participate in international tenders for technical and engineering works. What does the presence of such companies give to the country? Involvement in the global economy as a full value partner, but not " an assembly plant of foreign machines with foreign parts". What does a record in the international register get for an engineer? First of all, free choice – in life style, task complexity, country to live in, and income rate. The companies interested in hiring certified specialist have to pay salary "at the level of international standards". Isn't it the dream of any entrant who gives the results of his USE to the university admission office?

On such a modernized "skeleton" of basic conditions one can build up a package of recipes for intensive therapy of engineering education sounded many times both in our country and abroad [12, 13, 14]:

- renewal of mechanisms for wide youth's involvement in creative process – revival of existing in the Soviet period branched system of youth's vocational training (including numerous schools and clubs of research-engineering creative work etc.);
- extension of engineering competencies including multi-level extra vocational education for engineers wishing to get entrepreneur competencies (a reversed scheme is also possible – a businessman with economic background can get basic engineering skill through the system of appropriate extra training);
- upgrading of engineering education content, introduction of modern pedagogical techniques (project- and problem-oriented training), enhancement of academic mobility programs, post-graduate course upgrading, improvement of cognitive educational techniques, students' focusing at practical implementation of final projects; reasonable combination of traditional teaching methods with innovative ones.

Finance question is of importance too: increasing job prestige one cannot do without essential raise of average salary for this job. Industrialization and transfer to new innovative economy are impossible without

critical amount of people capable of designing, managing and supporting modern resource-efficient technical processes. Today there are slightly more engineers and designers of all fields than guards and less than service workers of hotels and restaurants [14].

The complex problems are solved by only a set of measures, but not partial actions at separate sites. To raise the prestige of a technician one should pool the interests: general-education school, higher school, business and government. Otherwise, there will not be those who would perform industrialization in the post-industrial world.

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