

Reproduction of Engineering Personnel for Innovative Economy: an Experience of Comparative Analysis

Liudmila Boronina
Institute of economics and management
Ural Federal University
Ekaterinburg, Russia
l.n.boronina@urfu.ru

Lyudmila Bannikova
Institute of economics and management
Ural Federal University
Ekaterinburg, Russia
l.n.bannikova@urfu.ru

Iurii Vishnevski
Institute of economics and management
Ural Federal University
Ekaterinburg, Russia
j.r.vishnevsky@urfu.ru

Aleksandr Baliysov
Institute of economics and management
Ural Federal University
Ekaterinburg, Russia
a.a.balysov@urfu.ru

Abstract — The inclusion of domestic technical universities in the international educational space (joining the Bologna process, participating in international University rankings, developing the academic mobility system) necessarily requires the implementation of comparative research projects, the formation and implementation of tools for comparability of organizational models and practices of self-determination of Russian and foreign universities concerning those institutional innovations that are associated with Industry 4.0. One of these projects, supported by the Russian Foundation for basic research, was initiated by a research group of the Ural Federal University. The aim of the study was a comparative study of the practice of introducing modern formats of engineering education in several European and Russian universities to analyze the dynamics of the institutional environment of modern engineering education. A comparative analysis of empirical research data in the practice of introducing new models of engineering education at partner universities made it possible to expand understanding of the specifics of the institutionalization processes of modern practices of training technical specialists for the digital economy, identify possible contradictions, “gaps” in the system of modern engineering education, and formulate proposals on smoothing out the most acute problems.

Keywords — *engineering education, institutional practices, comparative analysis.*

I. INTRODUCTION

In search for a solution of the stated scientific task of evaluating the effects of institutionalization of modern practices of technical training for the digital economy the research group had to form answers to a number of important questions to achieve the goal:

- What is the meaning of the concept “new format (new models) of engineering education”?

- What determines the new content of training programs for future engineers - new teaching methods, a new type of teaching, the use of digital technologies, online training, open education technologies?

- The search for an answer to the question of the timeliness and relevance of introducing new training formats precisely in engineering education has become no less significant.

- It was also essential for the authors to find an answer to the question of methodology and research. Assessing the dynamics of the institutional environment of modern engineering education for a small research team is an extremely complex and extensive topic, even though the team also included “practitioners” of engineering training: developers and experienced evaluators of engineering programs.

The main objectives of the first stage of the study: to analyze the socio-cultural conditions and social effects of the institutionalization process of innovative educational practices; to summarize the research and management foreign and domestic experience of studying the problems of reforming engineering education, including in specific countries, the theory and practice of institutional changes in the system of higher professional education; to identify the features and contradictions in the formation of the professional potential of future engineers in the context of ongoing changes in engineering education and the strategy of innovative development of the economy.

The results of the theoretical and empirical research made it possible to form answers to the questions posed and determine the directions of further research.

The leading regional and national universities of developed (according to the World Bank classification) countries (Germany) and developing countries (post-socialist Hungary,

the CIS countries – Belarus and the Russian Federation) acted in the status of “cases” and situations for institutional analysis.

As part of the implementation of the tasks of the pilot phase, an expert survey of representatives of the declared universities and a survey of engineering students of the Ural Federal University (UrFU) and the Hungarian University of Dunaujvaros (DUE) were conducted. The choice of universities to conduct the survey was determined by the similarity of areas of training of engineering personnel, post-Soviet country affiliation, target settings of universities, and the activity of introducing new formats of engineering education. Since 2011, UrFU has initiated training of a new generation of engineering personnel based on the principles and technologies of the international standards CDIO [1] – an integral part of the large-scale modernization of educational activities of technical universities in Russia. It is based on a competency-based approach, a modular learning structure, and practice-oriented educational technologies in partnership with large regional industrial enterprises. DUE is the first among Hungarian universities to receive an ISO 2001 2000 certificate that meets EU standards, as well as UrFU is a member of the European Erasmus program, and actively cooperates with regional partners of the private and public sector.

The survey was implemented in May-June 2018 using the Google Forms online application, as well as using the traditional printed version of the questionnaire in Russian and English. 310 students of undergraduate engineering programs such as mechanical engineering, materials science, and computer science were interviewed. The sample size is approximately one percent proportional to the number of undergraduate students in the listed engineering programs at each of the two universities. In the target quota sample, the country and the bachelor's STEM training program were used as quota attributes.

II. BACKGROUND

In modern society, the contradiction between the humanistic approach to education and the utilitarian emphasis on its role in economic development is resolved in the context of the approval of an innovative knowledge-based economy (“knowledge economy”). The most important factor in the formation of the knowledge economy is a qualitative change in the technological wave associated with the fourth industrial revolution [2]. The digital transformation of the economy inevitably expands the boundaries of traditional education. The monolithic and static system is replaced by a new one, where “the education process is continuous, and the learning paths are individual” [3]. At the same time, the knowledge economy is expanding on a global scale. Exteriorly, this is manifested in a sharp increase in the academic mobility of teachers and students, and an increase in the proportion of foreign teachers and students. But no less important are the processes of forming a single educational space (global [4], European [5], BRICS countries [6], [7] etc.) [8], [9], [10], [11]. Globalization also involves the convergence of educational policy objectives (including higher education).

The research of national higher education systems actively uses the approach of B. Clark, which is based on the

stakeholder theory [12]. The methodological and applied aspects of the interaction of subjects of the institutional environment of universities are disclosed in the works of N. V. Drantusova, A. A. Grisko, E. A. Knyazev, G. A. Rakhmanova, K. S. Solodukhin [13]. The stakeholder paradigm was used in the project of developing the classification and assessment of European universities U-MAP. However, the circle of stakeholders was practically narrowed to public associations (European Consortium of Innovative Universities, Association of European Universities, etc. [14]). The close connection between the two projects of the European consortium of researchers “UMAP” [15] and “U-Multirank” [16] contributed to the formation of tools for University comparability and research on the phenomenon of institutional diversity/differentiation and institutional isomorphism in the higher education system [17]. The main factors of institutional differentiation of higher education institutions are the expansion of students' educational needs, new requirements from the labour market, and modification of the functions of higher education institutions. The research tradition of institutional analysis of the organizational behaviour of universities is represented by the works of S. Albert, R. Wolf, J. Meyer, J. Olsen, S. Tolbert, B. Sporn. Organizational strategies and organizational changes of universities are studied in the works of E. V. Balatsky, A. O. Grudzinsky, T. L. Klyachko, E. A. Knyazev, Ya. I. Kuzminov, H. L. Titova, A. E. Chirikova, O. R. Shuvalova, A. Yakovlev. The results of research on the nonlinear model of Russian higher education in the region, implemented by a group of researchers led by Professor G. E. Zborovsky [18], are no less important for solving the problems of our study.

The stakeholder approach served as a methodological basis for modeling the technology for evaluating the social effects of the process of institutionalization of innovative practices for training technical specialists. The multiplicity of goals and, consequently, the multiplicity of results of professional education are determined by the interests of various social actors, explicitly or covertly presented in the social order for higher engineering education. In the context of evaluation activities, modeling has three functions: research, expert, and constructive. The development of a comprehensive model for evaluating the effectiveness of social effects of the process of institutionalization of innovative practices for training technical specialists was carried out using a synergistic modeling technique, which consists in the consistent application of structural, subject, and object approaches based on reengineering of the situation. The key concept of reengineering is the concept of the model usage scenario as a session of interaction between the research subject and the system, as a result of which the subject receives a certain product that has value for him. The method is based on two principles – the principle of inheritance and the principle of polymorphism. Methods of data processing are statistical data analysis and thematic text analysis, one of the modern ways of organizing modern research in the field of text analysis.

A sociological analysis of the professional potential of future specialists is implemented in the context of a community-based / subject, process, institutional and resource approaches. The community-based / subjective approach

allows performing a comparative analysis of the professional potential of students in technical areas of training object-by-object. The process approach was based on understanding the process and result of professional socialization of students as incomplete and open. Within the framework of the institutional approach, innovative features of the educational environment of each University, institutional specifics of pre-University training and the labour market that affect the process of professional potential formation were identified through self-assessments of students. The resource approach was used to identify the structure of professional potential of future engineers in the aggregate of three models – reserve, resource and intentional. The research strategy of complementarity methods, proposed by the research group, and interpretation of three concepts of professional potential of students in the corresponding models allowed us to identify the features of professional potential of students of two universities in the dialectic of "objective and subjective", "general and special", "past, present and future".

III. RESULTS

The need to reformat engineering education is especially relevant. This is not about modernizing an engineering education, but about the need for system reformatting, about a paradigm shift, transition from a narrow-profile technical specialist to an engineer with management skills who can solve system problems. Engineering is becoming more interdisciplinary and convergent. The educational paradigm is also changing in this direction. The focus is on three important aspects. The first is the training of thought activity and the formation of systemic thinking. The second focus is on engineering languages proficiency. The traditional universal mathematics language is complemented by knowledge of programming languages. Communication languages are of particular importance in the modern networked world. The engineer must be fluent in these basic languages when creating products and systems. The third focus is activity: to be able to act in conditions of uncertainty, in a world of increasingly complex technologies and unstable social structures, without disturbing the stability of the environment, to identify problems, model situations, and find and justify solutions.

Modern processes of radical transformation of universities with the development of digital technologies, the development of online learning lead to the emergence of a new type of teaching, the relationship of mentors and students, displacing traditional classes in the classroom. There are educational platforms, virtual academies for providing high-quality education to "everyone and everywhere". At the same time, MOOC courses, open education, according to Ben Nelson, does not change the format of learning, since they usually consist of standard University lectures that are caught on video. Reformatting professional education means, first of all, developing critical thinking, forming an active involvement of students in the learning process, their willingness to take responsibility for their education and their future. The formation of such motivation is a complex problem, and there is no simple solution. In this context, the introduction of new models and a new format of engineering education means

creating and developing a channel for the formation of the intellectual elite of society and the region.

Traditionally, issues of social effectiveness of higher education are considered at the theoretical level in the context of its social functions, and applied research is focused on studying students as a specific social group, assessing the degree of satisfaction with educational and leisure activities, the possibility of prospective employment, identifying value and professional attitudes, life and professional plans. Methodological issues of evaluating the effectiveness of educational practices are considered much less frequently. The study of the social effects of the introduction of a new format for training technical specialists assumed a methodological justification of the technology for their assessment. The construction of a criteria-based system for assessing the social effects of the institutionalization of innovative practices for training technical specialists is possible based on the identification of interests of stakeholders in engineering education – employers, government officials, university administration, educational program managers, teachers, students, and local communities.

Generalization and analysis of the training of modern engineers were carried out at the Technical University of Berlin, at the University of Dunaujvaros (Hungary, Dunaujvaros), at the Belarusian State University of Informatics and Radio Electronics (Minsk) and the Ural Federal University (Russia, Ekaterinburg). The experience of partner universities allows us to understand how the ideas of the Bologna process related to internationalization and the creation of a single educational space are implemented in specific universities and educational programs, and provide the basis for cooperation, ensuring academic mobility and network forms of partnership. Among the entire range of principles of the Bologna process, the most relevant issues for engineering education are quality assurance, i.e. building such social models of stakeholder interactions that provide prompt feedback not only on changes in technology but above all, on trends in the development of the industry. One important aspect of university performance, especially in countries where governments subsidize education, is the satisfaction of the labour market with the level of training of graduates.

Comparative assessment of the impact of modern approaches to organizing the training of engineers on the process of their professional socialization, is based on analysis of survey data of students STEM training two partner universities, expert interviews helped to identify the peculiarities and contradictions of formation and development of professional potential of future engineers in the modern formats of engineering education. An object-by-object analysis of the structure of the professional potential of UrFU and DUE students revealed a significant gap in the reserve characteristics of the professional potential of Ural undergraduate students. Administrative methods of planning staffing needs (changes in the structure of training, increasing the admission quotas to the technical field of study) in conjunction with low levels of pre-University training of applicants and low educational start (the Unified State Exam results), not only didn't alleviate the problem of shortage of engineering qualifications but also gave rise to the institutional

trap that promotes leveling and demotivation of professional choice of students.

The results of the study showed that in the learning process, the starting problems of the formation of the professional potential of students of UrFU, fixed in the reserve model, are partially neutralized. The level of representation of bachelors about the profession, general awareness of the nature of modern production and the specifics of its industries, the ability to navigate the range of technical professions concerning pre-University training increases 2.5 times, concerning the dynamics of professional representations of Hungarian students – 10 times. The positive dynamics of professional socialization of students in Ural Federal University is due to favorable resource characteristics of its educational environment, the quality of which is not inferior, but somewhere exceeds the similar characteristics of a European university: a good technical base of the university, laboratories and classrooms equipped with modern equipment; wide involvement of partners-employers to participate in the implementation of educational programs; connection of acquired knowledge with real work by profession; individual work of teachers with students; focus on active forms, methods and technologies of training, first of all, project training. However, rather high resource characteristics of the educational environment of the University can't fully compensate for the low initial level of preparation of applicants for technical programs. There is still a contradiction between the quality of the educational environment and the low level of efficiency of its development. The latter can't serve as a good basis for the formation of students' attitudes to increase their professional potential, to form the value of self-development.

A survey of students did not record an increase in professional potential among students of the technical magistracy of Ural Federal University. Retrospective assessments of the professional choice of master's students show that 40% of respondents have zero professional and educational start. For magistrands who immediately after graduation continued their education in specialized magistracy, such indicators indirectly reflect the low quality of education in undergraduate studies. For those who enter the master's program without a basic specialized education, the magistracy actually serves as a second higher education. Half of the respondents-magistrands continue to remain in the dark about their profession as well in the learning process. Following the Bologna model, master's education should be focused on in-depth professional training in a particular speciality, expanding the range of scientific, theoretical and applied competencies of students. If this happens with a certain part of magistrands, it is not due to the transition of technical education to level training, but to new formats of engineering education with all the relevant resource characteristics of the educational university environment, the introduction of which did not particularly require training levels.

The competitive advantages of the University of Dunaujvaros, according to students, are wide opportunities to study according to individual curricula and the implementation of individual educational paths; the active practice of

international exchange and academic mobility. It is these advantages that provide Hungarian students with higher grades of self-employment opportunities not only in the national but also in the international labour market.

In the study of the professional potential and quality of training of engineers, the effect of "double-humped" discrepancy was recorded, as well as to the same extent the presence of a deficit and surplus of qualification skills and labour market requirements. The recorded phenomenon fixes equal responsibility for the remaining "gaps" in the training of specialists in the system of higher professional education and employers who do not want to assume obligations for the preparation and implementation of the formed competencies. Combining work and learning in Russian practice is often implemented on the initiative of the students themselves. This combination often "does not work" to deepen professional training, rather, to solve the financial problems of the student, to acquire social skills and experience. The lack of practical professional experience reduces the confidence and competitiveness of future engineers in the labour market.

IV. CONCLUSION

The obtained results served as the basis for the formation of a number of practical recommendations.

Academic mobility as a factor in improving the quality of education is highly appreciated by students and experts. Mobility is a reserve of Russian education, a good incentive for the University itself to catch up, providing trainees with the best courses and strong teachers. For students, transferring to another University is extremely useful. At the same time, in Russia today, financial, administrative and mental (trust issues, complexity of module transfer) barriers to mobility development remain. One way to get around a number of barriers to academic mobility is to transfer it to online forms, implement internships and joint conferences.

No less significant for the university remains the problem of the starting level of training applicants for engineering specialities. In Russia, about a quarter of all applicants for STEM programs have an average score for the Unified State Exam below 56 out of 100 points. Solving or alleviating the problem can only be complex. One of the ways to solve the problem is to improve career guidance, starting not from school graduation classes, when the choice is already largely determined, but from the middle level of a secondary school, using the active involvement of employers in career guidance.

Professionalization in the framework of university educational programs is one of the significant factors in the training of engineering personnel, but at the same time, short-term programs that train certain competences (ideology lifelong learning) are becoming more and more popular. The modern interpretation of the profession involves the possession of a set of competencies, among which the ability to learn and improve their professional competencies is especially notable.

A practice-oriented approach, "dual learning" is more aimed at improving existing processes in engineering training than at radically transforming them. This approach allows

universities to maintain the necessary level of training, but does not provide a "breakthrough" in STEM education, does not work fully on "advancing", on the formation of future competencies. Professions appear and disappear today at such a speed that it is impossible to obtain professional competencies for life. The most demanded ones are people who are able to create something that does not exist, and for this, they must have a special, unique set of competencies. New non-standard forms of training, non-formal and informal education are emerging, such as the network University 20.35, the Minerva project, and more. It is necessary to continue joint research and prepare applications for grants that will allow for mobility, conduct joint conferences and research.

The prospects for research, respectively, can be associated with the expansion of the empirical base, as well as the use of qualitative research methods. As promising areas, we can highlight the impact of social norms, rules, statuses and roles set by new training models on the interests of interacting subjects of the educational process. Considering non-linear and multi-agent institutional effects of the impact of new educational practices on "interest groups" can become a tool for accompanying ongoing changes, identifying strengths and weaknesses of the system, overcoming the inertia of the existing institutional environment, mitigating contradictions, and identifying ways to reconcile the interests of all subjects of educational interaction, both representatives of education and practical engineering.

Acknowledgment

The research was supported by the Russian Foundation for Basic Research (RFBR), project № 19-011-00252 "Comparative analysis of social effects and the impact of institutional conditions on the training of engineering specialists"; Act 211 of the Government of the Russian Federation, contract № 02.A03.21.0006.

References

- [1] A.I. Chuchalin, T.S. Petrovsky, E.S. Kulyukina, CDIO Worldwide Initiative. Standards: information-methodical publication. Tomsk: Publishing House Tomsk Polytechnic University, 2011.
- [2] I. Peña-López, Rethinking Education. Towards a global common good? Paris: UNESCO, 2015.
- [3] K. Schwab, The fourth industrial revolution. New York: Crown Business, 2017.
- [4] "HEFEI statement on the ten characteristics of contemporary research universities" in LERU official site [Online]. Available: <https://www.leru.org/files/Hefei-Statement-Full-paper.pdf> [Accessed: 20-Jan-2020]
- [5] "Communication from the commission. The role of the universities in the Europe of knowledge" in EUR-Lex.europa.eu official site [Online]. Available: <https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2003:0058:FIN:en:pdf> [Accessed: 20-Jan-2020].
- [6] V. Urmas, "Entrepreneurship education in the higher education institutions (HEIs) of post-communist European countries", in Journal of Enterprising Communities: People and Places in the Global Economy, vol. 4, no. 3, 2010, pp. 204–219. doi: 10.1108/17506201011068219.
- [7] F.G. Altbach, G. Andrushchak, Ya. I. Kuzminov, M.M. Yudkevich & L. Raysberg, The future of higher education and the academic profession: BRIC countries and the USA, Moscow: Publishing. HSE house, 2013.
- [8] R. Shields, "Globalization and international student mobility: a network analysis", Comp. Educ. Rev., vol. 57, no. 4, pp. 609–636, November 2013, doi: 10.1086/671752.
- [9] O. N. Machekhina, "Globalization of education: the experience of retrospective complex analysis», International conference education environment for the information age (EEIA-2016), France, vol. 29, doi: 10.1051/shsconf/20162901047, June 2016.
- [10] W. Sunthonkanokpong, "Future global visions of engineering education", 2nd International Science, Social Science, Engineering and Energy Conference (I-SEEC), Thailand, pp. 160-164, doi: 10.1016/j.proeng.2011.03.029, 2011.
- [11] J. Ginzstler and Z. S. Zagoni, "Globalization of continuing engineering education and the Bologna process", in Annual 2007 of the Croatian Academy of Engineering, Z. Kniewald, ed. Zagreb: Croatian Academy Engineering, 2007, pp. 43–48.
- [12] B. R. Clark "The higher education system: Academic organization in cross-national perspective" in Journal of Policy Analysis and Management, vol. 3, no. 3. CA: University of California Press, 1983, pp. 466-466, doi:10.1002/pam.4050030317.
- [13] N. V. Drantusova and E. A. Knyazev, "European scales and institutional transformation in Russian higher education", in Journal of Educational Studies Moscow, no. 2, 2014, pp. 109–131.
- [14] Yu. A. Burdelnaya, "Institutional diversity in higher education: conceptualization of notions", in Modern Research of Social Problems, no. 12, 2015, pp. 154-161.
- [15] "Our Approach" in U-Multirank Project official site [Online]. Available: <https://www.umultirank.org/about/methodology/our-approach/>. [Accessed: 20-Jan-2020].
- [16] "Methodology - U-Map" in U-Map official site [Online]. Available: http://www.u-map.eu/methodology.doc/index.shtml#general_guidelines_and_design_pr. [Accessed: 20-Jan-2020].
- [17] E. Knyazev and N. Drantusova, "Russian system of higher education and its stakeholders: ten years on the way to congruence", in Higher Education in the BRICS Countries: Investigating the Pact Between Higher Education and Society, vol. 44, S. Schwartzman, R. Pinheiro, and P. Pillay, eds. Dordrecht: Springer, 2015, pp. 215–236.
- [18] G. E. Zborovsky, P. A. Ambarova, V. S. Katashinskih, A. K. Klyuev, A. A. Kuzminchuk, S. V. Kulpin, M.V. Pevnaya, N.V. Shabrova, E.A. Shuklina, Non-linear model of Russian higher education in the macro-region: theoretical concept and practical possibilities: monograph, G. E. Zborovsky, Ed. Yekaterinburg: Humanitarian University, 2016, 336 p.