Transforming requirements for engineering occupations as affected by technological changes

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Abstract. This article is devoted to studying the influence of technological changes on transforming the necessary set of skills for engineering occupations. The expected changes in qualification requirements for engineers is based on the analysis of industrial revolution. The growing importance of soft skills is acknowledged. The methodological conclusions regarding the need to take into account the level of triple helix awareness, along with the parameters of the labor market when forecasting the directions for qualification requirements transformation for engineers were substantiated. It is noted that being ahead in the formation of new skills may have a positive impact on the growth in innovative activity. It is this aspect of the relationship between technology and qualification development trends that determines the role of educational organizations in the innovation ecosystem. It is shown that the convergence of technologies leads to an expansion of the range of professions referred to as engineering. The use of particular tools for assessing the demand for competencies allows solving only situational research tasks, whereas in the meanwhile scientifically advanced ecosystems require a system for monitoring technological and qualification changes, primarily in relation to engineering qualifications, since they can become a “bottleneck” of technological development. A methodology for systematizing the influence of technological trends on the qualification requirements is proposed. The mentioned methodology is based on bringing into conformity reciprocal trends on the meso-level within the framework of triple helix cooperation on the regional scale. As the labor market acquires flow characteristics, the need for separate monitoring procedures will decrease, with analysis algorithm simplifying.

1. Introduction
Innovative development processes impose new requirements for skills and qualifications set of employees, which is particularly relevant for engineering occupations, since implementing new technologies relies heavily on staff members mentioned. Growing “intra-industrial rifts in capacity levels” [1] observed in Russia are largely caused by the rifts in skills. Nowadays high-tech and science-intensive companies are in need of “flexible” specialists capable of adapting swiftly to constantly changing technology, whereas conventional industries are to experience such necessity in the near future. Innovation economy demands not professionals, but rather “transfessionals” that have mastered
several vocations and are able to cross boundaries between these vocations if necessary. Education system is faced with a difficult task of foreclosing substantial gaps between skills developed in graduates and market demands, whereas in the case of engineering professions educational institutions need to aspire to proactive skills development.

Understanding the essence of technological changes can be ensured within the framework of several theoretical concepts, one of which being the concept of industrial revolutions. It is crucial to determine cause and effect relations, drivers behind industrial revolution and its ramifications for labor market. Disproportions in accumulating new expertise accompanied by a surge in inventions and the need for new sources of energy are widely acknowledged to be driving forces behind any industrial revolution. Consequences of industrial revolutions are imminently apparent in changing technological model, transforming infrastructure as well as in social and political shifts. It is crucial to learn how to implement inevitable changes in qualification requirements simultaneously with technological changes.

2. Methods
When researching the requirements for engineering occupations it is possible to single out two main directions determining methodological framework of the research. Within the first methodological direction main emphasis is placed upon the labor market, with main discussion subject being the gap between skills developed in the educational domain and qualifications demanded by the market. Although we acknowledge the presence of such gap, we agree with the opinion that given the features of the Russian labor market “it cannot be regarded as the locomotive hauling along the sphere of education in a proactive manner” [2]. Transformations in the labor market are stirred not only by technological innovations as such, yet by forward-oriented qualifications which initiate technological shifts. The second direction of studying qualification rifts is based on the “triple helix” (“quadruple helix”) model [3], systemic integration theory of G. Kleiner [4] and stakeholders interest equity approach. The features of interaction between innovation helix actors determine the need for defining qualifications both quantitively and qualitatively. Such definition serves as a prerequisite for developing innovations process ensuring capital flow to such domains and regions that have developed advanced engineering, managerial and entrepreneurial skills.

These two directions are not mutually exclusive or conflicting. Both of them are essential for defining and assessing disconformities between existing and required engineering qualifications in the environment of technological changes. With “employees’ aptitude for creativity” reinforced by up-to-date qualifications “being the main resource of postindustrial development”, proactivity in terms of skills developed in the educational sphere is bound to serve as a catalyst for innovative development. “Pressure” exerted by highly qualified professional may fuel innovation activities [6].

Among the methods of qualifications analysis employed in Russia, we need to highlight expert questionnaire, occupation profiling, trend analysis, sector- and region-specific differentiated analytics, comparative analysis, vacancies content analysis, key qualifications development method, gaps analysis. Each of the methods allow to solve a separate research task.

3. Results
Studying recent technological changes within the industrial revolution framework and pointing our the ongoing NBIC-convergence, various authors [7-8] suggest a number of technological trends. Technological shifts along with the corresponding requirements for engineering qualifications are listed below (table1). Analysis of qualifications shows a clear priority of soft skills, such as susceptibility to innovations [9], systemic and ecosystemic thinking, teamworking, creativity, project management readiness, operating within specified time limits and under circumstances of information overloads, multitasking. The results obtained are largely in accordance with the requirements listed by Atlas of new professions [10], CDIO concept [11] и a range of international documents [12-16]. In the documents mentioned a special emphasis is placed on developing engineering thinking implying a developed creative imagination, systemic information comprehension and a strong command of methodology used for technical creativity and new ideas generation.
Table 1. Technological shifts and their influence on qualifications requirements review.

| Area of the change       | Key technological trends                                                                 | Changes in the requirements for engineering qualifications                                                                 |
|--------------------------|-----------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|
| Information processing   | Growing data volumes, increasing complexity of data analysis methods and systems, built-in interaction capacity, convergence between information technology and material production technologies, removing constraints with respect to space | Information overload tolerance, multitasking, strong command of foreign languages, susceptibility to innovations, proactive creativity, teamworking skills, including remote mode operations, engineering analysis skills under strict restrictions with respect to time, ecology and economy |
| Management and self-management | Developing autonomous management and self-management systems, rising manageability of processes, employing self-governing systems to control individuals and social processes | Increasing demand for transformational, developmental, creative qualifications, priority of humanist values, strategic thinking, self-presentation skills |
| New materials            | Designing materials possessing pre-set features and memory effect, synthesizing materials and characteristics of various systems | Transfessional skills and knowledge, teamworking skills, proactive creativity, inventive and innovatory skills, strategic thinking, project initiating and launching activities |
| New management objects   | Multilevel manageability of processes and materials of various nature, smart materials and technologies (self-governance capacity and adaptation of resources) | Transfessional knowledge and skills, creative capabilities, teamworking skills, readiness to control the life cycle of a product at all stages including disposal, decision-making in uncertain environment |
| Products                 | Miniaturization and microminiaturization of products and their components, multifunctionality of products, designing brand new products for new market within the framework of blue ocean strategy | Understanding needs of the customers, new products promotion skills, project initiating and launching activities, inventive and innovatory skills, interdisciplinary knowledge, susceptibility to innovations |
| Resources                | Vast opportunities for the economy of resources, energy and labour as well as for recycling | Ecological expertise, ecosystemic thinking, ability to assess efficiency in terms of ecology and energy use, accounting for influence of innovations on the labor market, accounting for and adhering to ecological constraints |
| Features of technological systems | Humanizing the functions of technology, incorporating engineering solutions and technology in an integrated system suited to a simple control interface, production customization | Inventive and innovatory skills, systemic thinking, project initiating and launching activities, understanding needs of the customers, susceptibility to innovations, engineering and re-engineering skills |

Along with the presence of engineering type thinking, a profession can be qualified as an engineering vocation according to the criteria of the object of labor [17]. “Person – machinery” type professions can unequivocally be designated as engineering-related occupations, whereas “person – sign system” jobs can be partially qualified as such. As a result of converging technologies, engineering occupations have been broadened to overlap with other profession types, most notably with “person – nature” jobs.

One of the practical problems in this domain is difficulty in assessing qualifications at macro- and meso-levels of economy, and hence it is necessary to classify engineering occupations, develop a forecast of demand for engineering personnel with a breakdown into occupation clusters and substantiate the set of necessary soft and hard skills for the clusters mentioned. As an initial stepping stone, we used enlarged specializations and programs groups (ESPG or UGSN) implemented in a federal higher education standards systems. Alternative approaches based on professional standards, Russian National
Classifier of Economic Activities ОК 029-2014 or Russian Classifier of Occupations ОК 010-2014, were excluded from the research because of their fixation to the existing boundaries between industries.

While choosing enlarged specializations and programs groups, several contradictions arise. To start with, engineering personnel is not limited to ESPG 1 to 29. Furthermore, using ESPG itself is by default nominal, since switching over to the new standards happened several years earlier, and a great majority of the labor force has diplomas with different codes system for educational programs. Finally, it is impossible to adhere to the traditional notion of an engineering occupation being a “person – machinery” or, partially, “person – sign system” vocation, since most researchers list biotechnology among converging NBIC technologies and technologies of the future technical patterns, whereas corresponding education is not confined to engineering ESPGs from 1 to 29.

The proposed methodology for systematizing the influence of technological trends on requirements for engineering qualification includes the following stages:

- Initially ESPG should be brought into conformity with the regional economic structure, which ultimately leads to narrowing down the ESPG list.
- Sector-wise monitoring (within the boundaries of established industries) of newly emerging processes, including rival technologies from other industries. Localization of industries is predetermined by demand for special knowledge and data sources for conducting such analysis. The results of such analysis are partially reflected in new professional standards, and it is crucial to take into account the possibility of new occupation emerging at the stage of standard development. As a result, we obtain the list of technologies changing requirements for qualifications and boundaries of the industry.
- Monitoring of informatization and automatization processes while taking into consideration dislodgement of modification-oriented professions, emerging requirements for gnostic and exploratory vocations up to singling out new jobs. Such monitoring should be conducted at regional and/or sectoral scale, with trends abroad taken into account. Consecutively, we receive a list of obsolescent occupations and those professions that need requalification.
- Monitoring with the breakdown according to the largest employers is to be focused at the following:
  - investment projects meant for creating production plants belonging to new technological models generating demand for new occupations;
  - investment into expanding and modernizing the existing capacities that generate demand for more qualified staff;
  - projects of organizational changes (i.e. restructuration) that generally lead to increasing labor productivity by means of automation and rationalization of labor force and release of unqualified labor force.

As a result, the list of industries, technologies and occupations is corrected, with due consideration paid to project realization horizon.
- Aggregate assessment of the impulse of structural shifts. Consecutively, the results of stages 2-4 are summarized with respect to industries and occupations. In order to conduct a comprehensive study of structural shifts, indicators demonstrating the state of infrastructure enabling innovative activities, labor force availability, scientific developments efficiency and promotions, innovation expenditures, presence of well-developed designated programs and legislature regulating innovative development of the regional administrative system.
- Determining the conformity between ESPG list and perspective structure of regional economy and requirements designed by the labor market within the framework of assessment horizon.
- Expertise across sciences where searching activity is increased and emerging need for researchers possessing special qualifications. As a result, educational standards for master’s programs befitting the listed skills are defined.
• Monitoring emerging educational standards at the new studying directions. Consecutively, the decision is taken whether to include those standards in the list or not.
• Monitoring the vacancies and employers, requirements. As a result, new type of vacancies and demand dynamics with respect to new qualifications.
• Monitoring educational projects and interdisciplinary programs. employers, requirements. Consecutively, presence and significance of reverse influence of qualifications on innovative sectors development.
• Monitoring development of technological startups leading to assessing directions of innovation activities leading to a possible expansion in the innovative industries list.
• Structuring occupations classification as per ESPG according to two features: for conventional and high-tech innovative sectors of economy taking into account the situation in the region, with respect to reformatory, gnostic and exploratory occupations.
• Determining risk and development zones keeping in mind traditional, high-tech and innovative spheres of economy and with respect to profession (reformatory, gnostic and exploratory occupations).
• Forming initial list of professions and dividing it into groups with different employment patterns depending on situational factors which we suggest adding technological changes and completeness of triple helix to.
• Formulating a cluster of substantial qualifications with regard to and in advance to technological trends.

4. Discussion
Currently, the slow pace of innovations implementation and “negative overlap” of the helix actors create the need for detailed forecasts differentiating in terms of novelty versus conventionality of a job allowing for singling out our conventional, evolutionary new and promising occupations. The more labor market characteristics correspond to the flow model characterized by the high degree of awareness of triple helix actors and their “positive overlap”, the need for detailing the forecasts according to ESPG, industries, activity types is decreasing to the extent of utilizing the criteria of high/low qualification and more/less attractive employers. The methodology is to be implemented at a regional scale. Substantial distances and relatively low geographical mobility of the workforce in Russia, uneven economic and technological development of the demand in the region.

Drawing a conclusion, we need to note that nowadays quantitative methods for assessing demands of employers do not solve the problem of engineering qualifications deficit. The remaining unsatisfied disbalance between engineering staff and market’s unsatisfied demand for highly skilled engineers determines the equilibrium between principally new approaches allowing to regulate the balance between supply and demand in terms of qualifications requirements. Preemptive measures taken to prepare engineering personnel of the desired qualification creates impetus for innovative development and triple helix exploitation on a scale of a separate region.

References
[1] Smorodinskaya N V, Katukov D D and Malygin V E 2019 Shumpeterian growth theory in the context of the innovation-led transition of economies Journal of Institutional Studies 11(2) 60-78
[2] Temnitskij A L 2017 Modern youth in the difficulties of Russian labour market and education Russia reforming 15 91-108
[3] Smorodinskaya N V 2011 Triple Helix as a New Matrix of Economic Systems Innovation 4 66-78
[4] Kleyner G B 2011 2011 New theory of economic systems and its applications Bulletin of the Russian Academy of Sciences 81(9) 794-811
[5] Buzgalin A V, Grinberg R S and Kolganov A I 2015 Global world in deadlock Is there a way-out? Sociological studies 11 3-13
[6] Melnikova E V and Melnikova A A 2017 Special features of forecasting staff requirements for innovative and technological development within the framework of “triple helix” concept

Innovative development of the Russian economy: materials of X applied science conference (Moscow) 42-6

[7] Smorodinskaya N V and Katukov D D 2017 Key features and implications of industrial revolution 4.0

Innovation 10(228) 81-90

[8] Grinin L E and Grinin A L 2015 Cybernetic revolution and the sixth technological model

Historical psychology and sociology of history 1 172-97

[9] Kutuzova A V, Yarkova S A, Yakimova L D and Melnikova E V 2020 Innovative management: increasing innovative susceptibility of personnel

Krasnoyarsk Science 9(1) 125-45

[10] Luksha P, Luksha K, Peskov D and Korichin D 2014 Atlas of new professions

(Moscow: Skolkovo) p 288

[11] Dolzhenko R A 2017 CDIO concept as the basis of engineering education: interim results and directions for further use in Russia

News of the Ural State Mining University 2(46) 104-8

[12] Edström K and Kolmos A 2014 PBL and CDIO: Complementary models for engineering education development

European Journal of Engineering Education 39(5) 539-55

[13] Graduate Attributes and Professional Competencies 2013

International Engineering Alliance Graduate Attributes and Professional Competencies (Washington, Sydney, Dublin) p 16

[14] 2010 Skills supply and demand in Europe: Mediumterm forecast up to 2020

(Luxembourg: Cedefop Publications Office) p 128

[15] Desjardins R 2012 Better Skills Better Jobs Better Lives: A Strategic Approach to Skills Policies

(Paris: OECD Publishing) p 114

[16] Javifret P 2017 Competence requirements, assessment and development in industry

ENAEE Members Forum (Leuwen) 23

[17] Klimov E A 1995 Image of the world in various professions

(Moscow: Moscow State University Press) p 138