Software Engineering Education for Ensuring Russia's Priorities in the Digital Economy

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ABSTRACT

Attempts of Russian authorities to find proper place for national economy in global market and to diversify traditional patterns of production demand elaboration and implantation of software products as elements of digital economy with a strategic aim to create Russian innovative technologies, resources and managerial solutions. However, there are still numerous unresolved problems in this area, which restrain establishment of software engineering as an instrument for maintainability of Russia's competitiveness in global transparent digital economy. The key problem for our research is to elaborate reasons for absence of scientific qualification "software engineering", which is meant to provide training for specialists of the highest academic and research qualification.

CCS CONCEPTS

• **Social and professional topics**→Software engineering education

KEYWORDS

digital economy, software engineering, higher education, scientific specialties, PhD training.

1 Higher education for digital economy in Russia: priorities and reality

By the Order of January 6, 2015 No. 7-r, the Government of the Russian Federation approved the list of 104 disciplines and specialties for higher education which correspond to the priority of modernization and technological development of the Russian Economy [4]. The list included 3 8 disciplines for training of bachelors and masters, 35 specialties for training of specialists with higher education, and 31 specialties for training of highly qualified personnel (candidate and doctoral studies), which are primarily related to the development of the main technology areas in Russia, such as power industry; defense and security; aviation and rocket and space equipment; software and information management; medical industry and biotechnologies; nano-technologies and new materials; railway and motor vehicles. The Russian higher education institutes which implement the aforementioned disciplines receive special state support which is expressed in extended provision of resources and funds to support the education process, accelerated development and modernization of facilities and resources thereof, increase of scholarship allowances for bachelors, masters, specialists, postgraduate and doctoral students trained in such specialties and disciplines. It is also worthy of note that the share of priority specialties and disciplines included into the list approved by the RF Government is quite small in the total list of specialties and disciplines for training of bachelors, masters, specialists, post-graduate students, and doctoral candidates currently used for education in the Russian higher school and amounts to less than 15% in total. For example, only 38 disciplines or 20% of 188 ones implemented for training of bachelors and masters in the Russian higher school are included into the priority list. The situation with post-graduate education and doctoral studies is even more complicated. For example, the List of specialties of research scientists [2] approved by the Order of the Russian Ministry of Education and Science of 10.01.2012 No.5, on which the degrees of the candidate and the doctor of sciences are defended in Russia and the academic degrees of candidate and doctor of sciences are awarded, includes 424 scientific specialties, and the priority list of disciplines for training of postgraduate students and doctoral candidates approved by the RF Government only includes 31 items or approximately 7%. The aforementioned data show the importance of the higher education disciplines included into the priority list approved by the RF Government for the modernization and technological development of the Russian economy.

The analysis of the aforementioned order of the RF Government of 06.01.2015 No.7-r, the applicable Federal State Education Standards of the Russian system of higher education

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and the regulatory documents of the RF State Commission for Academic Degrees and Titles makes it possible to identify a serious systemic problem which currently exists in the Russian higher education system in relation to training of specialists in the sphere of Software Engineering. On the one hand, the Software Engineering discipline of bachelor and master training is included by the RF Government into the list of priority disciplines of modernization and technological development of the Russian economy which emphasize the importance and relevance thereof for further development of our country; on the other hand it turns out that no training of highly qualified personnel (postgraduate students and doctoral candidates) within the aforesaid discipline is currently performed. Moreover, Software Engineering is missing in the List of specialties of research scientists approved by the order of the Russian Ministry of Education and Science of 10.01.2012 No.5, which generally does not allow to defend candidate's and doctoral dissertations and award specialists in software engineering the degrees of candidate and doctor of sciences.

It is the authors' opinion that the creation of an information and communication infrastructure of future digital economy definitely requires not only good bachelor and master level specialists in the field of software engineering but also higher scientific qualification personnel – candidates and doctors of sciences – for whom software engineering is the subject of professional activity: they are the ones who shall initiate, develop, and perform management of future large-scale ICT projects in our country [6].

Analysis of the higher education in Software Engineering in Russia is done in the work [3].

2 Training in Software Engineering in Saint Petersburg State University

Saint Petersburg State University (SPbSU) by the Federal Law "On Education in the Russian Federation" has right to develop their own sets of educational standards, determine the structure and content of educational programs at their own direction at all levels of higher education. Saint Petersburg State University's own educational standard approved in 2014, is set up for each direction of training – bachelor, specialist, and master. Master includes several models: academic, academically-oriented and practice-oriented.

According to the license (2011), training of bachelors and masters in Software Engineering in SPbSU is conducted at the Mathematics and Mechanics Faculty under the programs No. 09.03.04 (for bachelors) and No. 09.04.04 (for masters). The following key departments of the faculty take part in the implementation of these educational programs: Software Engineering[1], Analytical Information Systems[2]; Computer Science[3], Parallel Algorithms[4], Operations Research[5], Programs include profile disciplines:

- Structures and algorithms for computer data processing
- Practice of Programming
- Software Engineering
- Computer Graphics
- Software Project Management
- Formal Languages and Automata Theory
- Databases
- Architecture of Computational Systems
- Algorithms and Complexity

The List of key professions of graduates:

- Programmer
- Software architect
- Database administrator
- Information Systems specialist
- Project manager in Information Technology
- Testing expert in the field of Information Technology
- Head of Software Development projects
- Technical writer
- Systems analyst
- Technical support specialist in Information and Communication Systems
- Systems programmer.

More than 30 professors - doctors of sciences - take part in the implementation of the programs, including: Andrey N. Terekhov[6] - Head of the Software Engineering department, Boris A. Novikov[7], Nikolay K. Kosovsky[8], Demyanovich Yu.K.[9], Vladimir O. Safonov[10], and others.

In addition to training in the area of Software Engineering for bachelors and masters, SPbSU provides postgraduate, masters and bachelor's training in a number of specialties close to the professional field of Software Engineering, among them:

- Educational programs for graduate students:
  - 02.06.01 - Computer and Information Sciences
  - 09.06.01 - Informatics and Computer Engineering
  - 27.06.01 - Control in Engineering Systems.
- Educational programs for the training of masters:
  - 01.04.02 - Applied Mathematics and Informatics
  - 02.04.02 - Fundamental Informatics and Information Technologies

[1] http://math.spbu.ru/en/chairs/dep11.html
[2] http://math.spbu.ru/SD_AIS/index.shtml
[3] http://math.spbu.ru/en/chairs/dep10.html
[4] http://www.math.spbu.ru/en/chairs/dep22.html
[5] http://math.spbu.ru/en/chairs/dep09.html
[6] http://www.math.spbu.ru/user/ant/
[7] http://www.math.spbu.ru/user/boris_novikov/index.shtml
[8] http://www.math.spbu.ru/user/kos/kos.html
[9] http://www.math.spbu.ru/parallel/demjanovich_priv_en.php
[10] https://sites.google.com/site/vosafonov/

- 02.04.03 - Information Systems Administration and Mathematical Support
- 03.04.01 - Applied Mathematics and Physics
- 09.04.03 - Applied Informatics
- 27.04.03 - Systems Analysis and Control
- 38.04.05 - Business Informatics.

- Educational programs for bachelor's training:
  - 01.03.02 - Applied Mathematics and Informatics
  - 01.03.04 - Applied Mathematics
  - 02.03.01 - Mathematics and Computer Science
  - 02.03.02 - Fundamental Informatics and Information Technologies
  - 02.04.03 - Information Systems Administration and Mathematical Support
  - 03.04.01 - Applied Mathematics and Physics
  - 09.04.03 - Applied Informatics
  - 27.04.03 - Systems Analysis and Control.
  - 38.04.05 - Business Informatics.

The implementation of educational programs for training of masters and bachelors in the areas of Fundamental Informatics and Information Technology and Systems Analysis and Control is carried out by the following departments of the Faculty of Applied Mathematics–Control Processes: Computer Applications and Systems [11], Computer Modelling and Multiprocessor Systems [12], Electromechanical and Computer Systems Modelling[13].

Educational programs for the training of masters and bachelors in the direction of Business Informatics are implemented at the Faculty of Economics of SPbSU by the Department of Information Systems in Economics[14]. Basic courses of this educational program, correlating with those listed in the Software Engineering Body of Knowledge SWEBOK [1], are as follows:

- Databases
- Object-Oriented Analysis and Programming
- Business Information Analysis
- Information Systems
- Analysis and Modeling of Business Processes
- IT-infrastructure Management
- Simulation Modeling
- Decision support systems
- Decision theory.

According to the statistics of the period of 2011-2018, the graduates worked in the following positions:

- Database administrator
- Computer Network administrator
- Business analyst
- Systems analyst
- Specialist in the Implementation of Information Systems
- Systems programmer
- Information Systems designer
- Information Systems consultant
- Service engineer for Information Systems
- Economist in Planning
- Director for Economics,

that is, in the professions which create the digital economy of the future.

It should be noted nevertheless that the educational standard at the level of training of highly qualified personnel in Software Engineering – PhD-doctorate – in the Saint Petersburg State University is currently missing

3 European cooperation

SPbSU uses various forms of international cooperation for the preparation of highly qualified specialists, such as the Agreement for Double Doctoral Degree between Lappeenranta University of Technology and Saint Petersburg State University signed in 2016. This agreement makes it possible to PhD-students and applicants from both the universities to defend their scientific degrees at the dissertation councils of the SPbSU and get the PhD diplomas of the two universities-partners, in all licensed specialties, including SWE. Moreover, international cooperation in the field of higher qualification scientific personnel training is supported by the project *Joint Programs and Framework for Doctoral Education in Software Engineering (PWs@PhD)* in the European Union Erasmus+ Program *Capacity Building in Higher Education*[15].

4 Particular features of training of specialists in Software Engineering

Analysis of national and foreign practice of personnel training in software engineering shows that such training has a number of specific features [7]. Being inter-disciplinary in essence, it includes dozens of areas of knowledge, from fundamental (mathematics, informatics, modeling) to technical and technological ones: software design, development processes, software product management, etc. Acquisition of necessary competencies in the latter fields is impossible without participation in designers' teams working under real projects. The long-term practice of training of such specialists by the Software Engineering department of Saint Petersburg State University gives evidence [8] to the fact that success can be achieved when the industry requirements for IT specialists are duly taken into account in the training process organization; the Russian and international standards are used as a methodological

[11] http://www.apmath.spbu.ru/ru/structure/depts/kts/
[12] http://www.apmath.spbu.ru/ru/structure/depts/kmms/
[13] http://www.apmath.spbu.ru/ru/structure/depts/mems/
[14] http://www.spbu-bi.ru/ru/
[15] http://fase.it.lut.fi/

base of training; support of training by enterprises acting both as participants in the training process and as interested consumers of trainees is ensured; finally, when the technological platform for educational and scientific activity is a state-of-the-art technology park on the basis whereof the future software engineering specialists in teams of professional developers take part in preparation and implementation of relevant ICT projects. The method of training of fledgling specialists in the field of software engineering based on essential combination with on-the-job training in software companies has proved to be economically justified, strongly sought-for, and was taken on board not only by national universities but also by foreign IT companies [9].

It is impossible to educate a software engineer by using traditional method "with chalk at a black-board" [10]. One of the main differences of software engineering from informatics is the work with people. Large software packages and products are created by large teams for long periods of time. A software engineer must be able to plan the time limits and the budget of a project, provide necessary machines and other resources to its team. In addition, some issues or conflicts within the team occur on a day-to-day basis, problems with customers may frequently arise: all these may only be learned in practice.

The development of the system of student projects guided by employees of both local and foreign IT companies started in the Software Engineering department of SPbSU many years ago. Each project is managed by at least two employees of an IT company (one of them may fall ill or go away on business, but the training process may not be interrupted). Those employees offer subjects interesting for their companies, and the department makes sure that the subject should be adequately science-intensive. The whole process is organized in compliance with industrial practices: planning, weekly reporting, tracking, configuration management, QA (quality assurance), and team work. We think that this is a win-win situation: the students receive additional industrial education in the IT sphere totally free of charge; the university, again totally free of charge, obtains professional supervisor of term and graduate papers and access to state-of-the-art technologies (if an IT company employee conducts a class on a certain subject, any student or even any faculty member interested in such subject may attend such a class). Finally, the enterprise which certainly spends money for payment of salary to its employees providing training to the students will obtain employees who will be able to start creative work at the enterprise without any additional training.

Management of student projects is an excellent school of training of software engineers able not only to perform programming but also to lead teams.

The peculiarities of training and the specific features of operating activity of software engineers resulted in the separation of the respective specialty as an independent one and in the development of federal educational standards for training of bachelors and masters in the Software Engineering discipline. In the course of training of specialists with higher scientific qualification in the field of software engineering, fundamental and technical fields of knowledge are essentially supplemented by non-trivial competencies in production economics and research and development management, and the production component shall ensure gain in experience of management of software projects and scientific research in the field of information and communication technologies.

5 Problem

In Russia there is still no scientific specialty exactly named Software Engineering for the training of post-graduate students and doctoral candidates [2].

The Russian scientific specialty closest to the foreign Software specialty on which PhD theses are defended is specialty 05.13.11 – Mathematical Support and Software of Computers, Complexes and Computer Networks (technical sciences). the passport of such scientific specialty states that theses defended in this specialty shall contain results ensuring improvement of the efficiency of data and knowledge processing operations in computers, complexes, and computer networks and the reduction of their time, and the scientific degrees of candidate and doctor of technical sciences shall be awarded for research studies which result in substantial technical effect when the results are used and implemented. The comparative analysis of competencies of specialists who defend dissertations in the specialty 05.13.11 with those of a specialist in the field of software engineering as required by the SWEBOK, proves that 77% of such competencies are the same.

Table 1. Comparison with competencies of a specialist in software engineering

Specialty / Competencies	05.13.11	08.00.13	08.00.05
Economic			
Fundamentals of economics		+	+
Life cycle economics		+	+
Risk and uncertainty estimate		+	+
Methods of economic analysis		+	+
Computational			
Problem solving methods	+	+	
Abstractions	+	+	
Fundamentals of programming	+	+	
Knowledge of basic programming languages	+		
Debugging techniques and	+		

tools			
Data representation and structure	+	+	
Algorithms	+	+	
Fundamentals of systems analysis	+		+
Computer organization	+		
Basics of compilation	+		
OS basics	+		
Database and data management basics	+	+	
Basics of networks	+		
Parallel and distributed computation	+		
Requirements analysis			
Human resources management			+
Information safety and support	+	+	+
Mathematical			
Sets, relations, functions	+	+	
Fundamentals of logic	+	+	
Hypothesis testing	+	+	
Graphs and trees	+		
Discrete probability	+	+	
Finite state automation	+		
Theory of numbers	+	+	
Algebraic structures	+		
Engineering			
Empiric methods and experimental techniques			
Statistical analysis	+	+	+
Measurements	+	+	
Engineering design			
Modeling, simulation, prototyping	+	+	+
Cause analysis	+		
Total competencies: 35 (100%)	**Coinciding: 27 (77%)**	**Coinciding: 19 (54%)**	**Coinciding: 9 (26%)**

6 Proposals and prospects

The result of a system analysis of the 2017-2030 Strategy of the Development of an Information Society in the Russian Federation approved by the Executive Order of the Russian President of May 9, 2017 No.203 and the national program "Digital Economy of the Russian Federation" approved by the Order of the Government of the Russian Federation of July 28, 2017 No.1632-r, which was conducted by professors and PhD Software Engineering candidates of the System Programming Department and the Department of Information Systems in Economics is as follows:

1) Substantiation of critical importance and necessity of the development of software engineering to ensure competitiveness of Russia under the conditions of transition to digital economy. Disclosure of the essence and particularities of software engineering as a backbone component for the creation of an information society in Russia.

2) Identification of key issues of the development of software engineering in Russia (mathematical and technological support, software and hardware, personnel training, management, financing, regulatory support, government control, etc.). Identification of software engineering development management risks in the digital economy environment.

3) Comparative analysis of the Russian and international experience of training of highly qualified specialists in the field of software engineering. Identification of existing problems related to training of highly qualified specialists in the field of software engineering for the digital economy of Russia. Identification of management risks in the Russian high school within the context of opening of a new scientific specialty and creation of a favorable management system [20] in the leading Russian universities for effective training of specialists of higher scientific qualification – PhD specialists (candidates and doctors of sciences) in the field of Software Engineering.

4) Preparation and substantiation of recommendations for the improvement of the system of training of highly qualified personnel in the field of software engineering in Russia to respond to the challenges of digital economy. In particular:

- Draft application to the Ministry of Science and Higher Education of Russia for the inclusion of the new scientific specialty "Software Engineering" to the Nomenclature of Specialties of Scientific Workers. This will make it possible to defend MPhil and PhD theses and award academic degrees of MPhil and PhD in the specialty "Software Engineering". The addition of the currently missing research degree in the Software Engineering discipline to the two existing levels of higher professional education (bachelor's degree and master's

degree) will become an important backbone solution-creating environment for training of personnel meant to implement various ICT projects of the digital future.

- The project of the Federal State Educational Standard of higher education in the Software Engineering discipline (the level of highly qualified personnel training) for approval thereof by the order of the Ministry of Science and Higher Education of the Russian Federation[16] .

- Application for the creation of a single pilot postgraduate and master school for training of highly qualified personnel in Software Engineering discipline. Training of graduate and postgraduate students in such pilot school of SPbSU in Software Engineering discipline will promote emergence and implementation of the following synergetic effect: integrated simultaneous acquiring of knowledge and skills not only in theory but also in real practice, which in its turn will ensure their effective participation in the generation of digital economy in our country. The general possibility of taking specific steps for practical implementation of such a decision is provided by sub-clause 3.6.3 of the Road Map (p. 49) of the Order of the RF Government of July 28, 2017 No.1632-r "On approval of the state program "RF Digital Economy", which provides for the creation of pilot postgraduate and master schools in disciplines of "cross-cutting" technologies which certainly include software engineering, on.

CONCLUSION

From our point of view, implementation of the above listed proposals will make it possible to drastically improve the system of highly qualified personnel training in the field of software engineering in the Russian higher school in the near future, which in its turn will allow to create a real digital economy ecosystem in Russia for the development of high-technology businesses, platforms, and technologies as well as a favorable and safe environment for effective communication of market entity, economic sectors, the academic society, the state, and citizens.

[16] Approval of federal educational standards of higher education in Russia falls within the competence of the Ministry of Science and Higher Education of the Russian Federation, see, e.g. the Order of the Ministry of Science and Higher Education of the Russian Federation of 30.07.2014 No.875 "On approval of the federal education standard of higher education in the training discipline 09.06.01 "Informatics and Computer Engineering" (highly qualified personnel training level)"

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