Software Engineering Education in Russian Federation: Specifics of Bachelor, Master, and Postgraduate Study Programs*

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Abstract. The article examines the education system in the direction of "Software Engineering" in Russia for bachelor's, master's and postgraduate studies. The results of the analysis of Federal state educational standards in the direction of "Software Engineering", based on the comparison of competencies to the international body of knowledge on software engineering SWEBOK are presented.

Keywords: Software Engineering · SWEBOK · Russian federal state educational standard (FSES) · competencies

1 Introduction

Currently, all the programs of higher education in Russia are regulated by the Federal State Educational Standard (FSES) that defines a range of requirements to the educational program, including a list of competencies, skills, and areas of knowledge, which students should gain before the graduation. Higher education in the field of software engineering is not an exception.

Currently, there are FSES for bachelor's and master's degrees in the "Software Engineering" direction: 09.03.04 for bachelor's degree and 09.04.04 for master's degree [12]. These are detailed documents defining the scope and contents of the core base of knowledge as well as the volume of university-specific material reflecting its personnel and scientific requirements and needs of the regional industry. These standards are flexible and provide more opportunities for the expansion and deepening knowledge, skills and competencies for successful professional activity and further studies in postgraduate school.

As for the third level of higher education, namely training of highly qualified personnel, presently in Russia there is no any FSES in "Software Engineering". There are three related areas of knowledge which Ph.D. students can study: 02.06.01 "Computer and Information Technologies", 09.06.01 "Computer Science and Engineering" and 27.06.01 "Engineering Systems Management" [12]. FSES for postgraduate captures only the volume for professional cycle disciplines without specifying the content and features of the educational program.

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Finishing graduate school in Russia today doesn't necessarily include Ph.D. theses defense and therefore getting a Ph.D. degree. While studying at graduate school, students can select a specialty to prepare and defense Ph.D. theses. The analysis of the official Russian dissertation library (http://diss.rsl.ru/) over the past 10 years reveals that the majority theses in Software Engineering were defended within two specialty directions: 05.13.11 "Mathematical Support and Software for Computers, Computing Complexes and Networks" for theses concerning mathematical and technical aspects of software design, testing and construction and 08.00.05 "Economics and Management of National Economy" for theses devoting to software management [14].

Thus, the current Russian circumstances in the field of higher education in software engineering make it possible to perform an effective analysis of the FSES coupled with the programs for bachelor's and master's degrees from the Russian leading universities. This analysis will reveal how the programs cover the contents of SWEBOK [11], a body of knowledge on software engineering supported by IEEE and ACM and accepted in most developed countries for training and certification in the field of software engineering.

2 Related Work

The issue of compliance with the educational standards requirements of employers is one of the most important in Russian and international education to date. To analyze this problem in the field of Software Engineering, several researchers resorted to the comparison of the competencies obtained by the graduates with the recommendations presented in the SWEBOK – "Software Engineering Body of Knowledge" [11]. SWEBOK V3.0 is an updated guide describing the body of knowledge (15 areas) on software engineering jointly organized by the organizations IEEE Computer Society and ACM (Association for Computing Machinery). SWEBOK V3.0 today is the most authoritative guide to the fundamental knowledge of the profession of software engineering and adopted in most developed countries for training and certification in the field of software engineering.

Authors of [2, 3, 4] provide results of research in the field of competencies and knowledge that should be possessed by graduates of the "Software Engineering" direction based on the comparison of curriculum content with the SWEBOK topics. The authors of [3] have developed an expert system that enable companies to select the most suitable candidates for their jobs, considering personal and social skills, along with technical knowledge.

On the other hand, authors of [5, 6] argue that the structure of the SWEBOK can't be a strict requirement for the structure of the educational programs in software engineering. The author of [5] presents the following five specific comments-traps, based on the idea of crowding out on human and social aspects of the technical component of the training of software engineering based on SWEBOK:

1. A software engineering course needs an industrial project. The introduction of a real industrial project in training is not useful for the student because of

the overload of students in junior courses by programming disciplines. The author calls to simplify the program, by making a gradual introduction of students into software engineering, as possible.

2. Software engineering is like other branches of engineering. The author persuades to develop student's social competencies, along with technical knowledge, for their better adaptation in professional life.
3. Planning in SE is poorly done relative to other fields. The article gives examples of real well-known projects that are economically inefficient due to inaccurate planning. Risk management, according to the author, is the most critical area in software engineering, which requires the attention of students.
4. The user interface is a part of a low-level design. In the SWEBOK little attention is devoted to the user interface design, which influences the functionality of the system and improves it. Curricula for software engineering should include at least a course on the introduction of Human-Computer Interaction.
5. SWEBOK represents the state of the practice. The SWEBOK lags behind the state of the practice in some areas and runs ahead of the herd in others. Outpacing reality, in the future, lead to an even greater distance between the university and industry, because industry prefers evolution over revolution.

In [7, 9] authors introduce a model of development of software engineering student's competencies through vocational training. They propose a model of universal competencies as a requirement to the intellectual foundation of a professional software engineer.

The paper [8] discusses changes in the final version of the SWEBOK V3.0 (adopted and published in December 2013), as well as the emergence of new documents such as the SWECOM competency model (January 2014) [15] and the change in the IEEE CS professional certification system. On the basis of the analysis, a model of the profession is built.

In [10], the technology of development of the IT education system was considered on the basis of the internationally standardized curriculum. The analysis of the current state of the international standards of programs for the preparation of bachelors and masters in the field of information technology is given. Recommendations are given on the use of foreign experience in the development of the national IT education system.

Thus, the rapid development of the fields of knowledge of software engineering requires the constant update of educational standards and a curriculum for the preparation of students adapted to real industrial tasks. The identification of the best professional competencies, the analysis of existing curriculum and the formation of recommendations for the training of software engineering, which reduce the distance between university knowledge and the requirements of industry, is an urgent area of research not only in Russia but also in the world.

3 SWE in Russian Federal Bachelor's Standard

Russian federal state educational standard (FSES) in software engineering explicitly defines the minimum list of skills and competences which all graduates in direction 09.03.04 "Software Engineering" should obtain, as well as specifies the structure and scope of the educational program. In addition to the minimum requirements for the results of the program, the standard provides the possibility of supplementing the set of competencies based on the program orientation in specific areas of knowledge and/or professional activities.

According to the standard, all the skills and competencies are divided into 3 groups: general cultural, general professional and professional ones.

3.1 General Cultural Competences (GC)

General cultural competences are not professionally oriented; on the contrary, they are to relate to all graduates regardless of the activity area as they form the basis for training and further implementation [1].

Among the general cultural competencies the most attention should be paid to the following skills:

- use of economic fundamentals (GC-3) and legal knowledge (GC-4) in various spheres of life;
- communication in oral and written forms for solving problems of interpersonal and intercultural interaction (GC-5);
- teamwork (GC-6);
- self-organization and self-education (GC-7).

Analysis of the contents of these competencies allow us to conclude that they cover the following chapters in SWEBOK body of knowledge: Software Engineering Economics (Chapter 12) and Software Engineering Professional Practice (Chapter 11).

3.2 General Professional Competences (GPC)

The GPC chapter include skills and knowledge for graduates in broad fields of computer science and software engineering. The following skills can be referred: possession of basic concepts, principles, theories, and facts of Informatics (GPC-1), knowledge of computer architecture and systems (GPC-2) and basics of programming (GPC-3). Direct correspondence is found in SWEBOK chapters Computing Foundations (Chapter 13) and Mathematical Foundations (Chapter 14).

3.3 Professional Competences (PC)

PC establish restricted scope for software engineers reflecting professional requirements and demands. Professional competencies mentioned in the federal standard can be divided into nine subgroups, somewhat covering the following chapters of SWEBOK:

1. Software Requirements (Chapter 1) - formalization of the software domain, specification development for software components (PC-16);
2. Software Design (Chapter 2) - basic techniques and software development tools (PC-1), various software development technologies (PC-3), programming interfaces development (PC-22);
3. Modeling (Chapter 9) and Software Construction (Chapter 3) - modeling skills, analysis and use of formal methods for software implementation (PC-19);
4. Software Maintenance of (Chapter 5) - basic concepts and models of software evolution and maintenance (PC-10), peculiarities of evolutionary activity (inherited systems, reflexive planning, reengineering, migration, and refactoring) (PC-11), reading and understanding of the source code and documentation (PC-21);
5. Software Engineering Management (Chapter 7) - classical concepts and models in project management (PC-6), control software development (PC-7), project control (PC-9);
6. Software Engineering Process (Chapter 8) - standards and models of life cycle (PC-5);
7. Software Quality (Chapter 10) - concepts and attributes of software quality (reliability, safety, usability), including the role of people, processes, methods, tools and quality assurance techniques (PC-4);
8. Group Dynamics and Psychology (Chapter 11.2) - basics of group dynamics and psychology specific to software engineering (PC-8);
9. Software Engineering Economics (Chapter 12) - initial assessment of software project difficulty, risk and cost; working plan formation (PC-17); Preparation of commercial proposals (PC-18);
10. Computing Foundations (Chapter 13) and Mathematical Foundations (Chapter 14) - the use of operating systems, network technologies, various languages and formal specification methods, database management systems (PC-2), evaluation time and space complexity of the software (PC-20).

Table 1. Compliance of the FSES for bachelor's with the chapters of SWEBOK

Chapter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Competence	+	+	+	+	+	−	+	+	+	+	+	+	+	+	−

The analysis showed that the FSES of the bachelor's direction 09.03.04 "Software Engineering" covers SWEBOK by 87 % (table 1). The following two SWEBOK sections are not included in the standard:

1. Software Configuration Management (Chapter 6);
2. Engineering Foundations (Chapter 15).

4 SWE in Russian Federal Master's Standard

To review the federal standard of master studies in the field of software engineering, we would also analyze the minimum required competencies of graduates in the general cultural, general professional and professional spheres.

4.1 General Cultural Competencies (GC) and General Professional Competencies (GPC)

Among the general cultural and general professional competencies, it is worth paying special attention to the ability to self-education (GC-3), acquisition by means of information technologies, new knowledge and skills in new areas of knowledge (GC -7), possession of methods and means of obtaining, storage, processing and transmission of knowledge through modern computer technology (GPC-5). These competencies can be related to the "Software Engineering Professional Practice" (Chapter 11). Also, much attention is paid to the skills of organizing research and design works and team management (GC-5).

In addition to the above competencies, the standard presupposes the possession of modern methods of scientific research (GC-3) and the preparation of reports on the conducted research work, including the preparation of publications (GC-9) and compilation of analytical reviews with valid conclusions and recommendations (GPC-6). It is worth saying that the competencies relating to research activities, are not directly mentioned in the body of knowledge for a software engineer.

4.2 Professional Competencies (PC)

With regards to the professional competencies of master of software engineering, the Federal standard places particular emphasis on the mastery of methods and algorithms of decision of tasks of recognition data and data processing (PC-4), including digital signals processing (PC-5), and their subsequent design and software implementation (PC-15); the design and software implementation of distributed information systems (PC-7, PC-13) and high-performance systems with parallel data processing (PC-8, PC-14). Much attention is paid to the design and programming capabilities of translators and interpreters of programming languages (PC-9, PC-16), network services (PC-10, PC-17), the main components of operating systems and real-time systems (PC-11, PC- 18), systems for creating three-dimensional images (PC-21), designing auxiliary and specialized programming languages and data representation languages (PC-12). The above competencies cover the Software Design (Chapter 2) and Software Construction (Chapter 3) sections on software design and software implementation, as well as the sections of the Computing and Mathematical Foundations (Chapter 13 and Chapter 14) reflecting more specific knowledge on the basics of data representation and processing and the organization of computing system with different architecture.

Knowledge of software verification approaches (PC-6), which are part of the Software Quality section (Chapter 10), and the organization of industrial testing of the created software (PC-20) from the Software Testing section (Chapter 4) are also mentioned in professional competencies.

Table 2. Compliance of the FSES for master's with the chapters of SWEBOK

Chapter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Competence	−	+	+	+	−	−	−	−	−	+	+	−	+	+	−

FSES of the master's direction 09.04.04 "Software Engineering" covers SWEBOK by 47 %. The following SWEBOK sections are not included in the standard:

1. Software Requirements (Chapter 1);
2. Software Maintenance (Chapter 5);
3. Software Configuration Management (Chapter 6);
4. Software Engineering Management (Chapter 7);
5. Software Engineering Process (Chapter 8);
6. Software Engineering Models and Methods (Chapter 9);
7. Software Engineering Economics (Chapter 12);
8. Engineering Foundations (Chapter 15).

Master's education assumes a basic bachelor's degree in software engineering. That allows to consider the competencies of the standard for master's, as addition to the competencies of the standard for bachelor's software engineering. Then, the overall coverage of the SWEBOK chapters is 87 %. "Software Configuration Management" and "Engineering Foundations" are not covered in the standards.

5 SWE in Russian PhD Education

FSES for postgraduate studies forms a program for training highly qualified personnel in various areas. FSES for postgraduate study in the "Software Engineering" direction does not exist. Graduate students can study in the following two areas, close to software engineering:

– 09.06.01 Computer science and engineering;
– 02.06.01 Computer and information technologies.

FSES in the directions of postgraduate study is a list of universal and general professional competencies that a graduate of graduate school should receive. But FSES does not define the list of professional competencies. Professional competencies are determined by the specialty, for which academic degrees are awarded.

In Russia, the degree of candidate or doctor of science is awarded by the Higher Attestation Commission (HAC), the state body under the Ministry of Education and Science of the Russian Federation, on the recommendation of the Dissertation Council. Under the guidance of the Higher Attestation Commission in some Russian universities, Dissertational councils have been formed, carrying out work on certain specialties.

The analysis of the official Russian dissertation library (http://diss.rsl.ru/) over the past 10 years reveals that the majority of theses in Software Engineering were defended within two specialty directions:

1. 05.13.11 "Mathematical Support and Software for Computers, Computing Complexes and Networks" - theses on the mathematical theory of programming, creation, maintenance and operation of software for various purposes for computers and computer systems, as well as complexes built on their basis, computer and neural networks.
2. 08.00.05 "Economics and Management of National Economy" - theses in the field of management of software development projects.

The field of research in each specialty is determined by the specialty passport developed by the HAC. The passport of the specialty is a document that fixes the field of research for which a scientific degree of a candidate or a doctor of sciences in the relevant specialty can be awarded.

The passport of the specialty 05.13.11 "Mathematical Support and Software for Computers, Computing Complexes and Networks" includes the following professional competencies, covered by the chapters of SWEBOK:

1. Models, methods and algorithms for the design and analysis of programs and software systems, their equivalent transformations, verification and testing cover 3 chapters of SWEBOK – "Software Design" (Chapter 2), "Software Testing" (Chapter 4) and "Mathematical Foundations" (Chapter 14).
2. Programming languages and programming systems, program semantics - relate to the "Computing Foundations" (Chapter 13).
3. Models, methods, algorithms, languages and software tools for organizing the interaction of programs and software systems are reflected in SWEBOK Chapter 9 "Software Engineering Models and Methods", and partly in Chapter 13 "Computing Foundations" and "Mathematical Foundations" (Chapter 14).
4. Database and knowledge management systems, software systems of symbolic computing and operating systems also affect the 13th chapter "Computing Foundations".
5. Human-machine interfaces; models, methods, algorithms and software tools for computer graphics, visualization, image processing, virtual reality systems, multimedia communication – "Software Design" (Chapter 2), "Software Construction" (Chapter 3), "Computing Foundations" (Chapter 13).
6. Models and methods for creating programs and software systems for parallel and distributed data processing, languages and parallel programming tools - "Computing Foundations" (Chapter 13) and "Mathematical Foundations" (Chapter 14).

7. Models, methods, algorithms and software infrastructure for organization of globally distributed data processing - “Software Engineering Process” (Chapter 8).
8. Quality assessment, standardization and maintenance of software systems are covered in chapter 5 “Software Maintenance”, chapter 7 “Software Engineering Management”, chapter 10 “Software Quality”.

Thus, the passport of the specialty 05.13.11 “Mathematical Support and Software for Computers, Computing Complexes and Networks” covers the following chapters of SWEBOK.

Table 3. Compliance of the FSES for 05.13.11 postgraduate specialty with the chapters of SWEBOK

Chapter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Competence	−	+	+	+	+	−	+	+	+	+	−	−	+	+	−

Analysis of the specialty passport 05.13.11 “Mathematical Support and Software for Computers, Computing Complexes and Networks” showed SWEBOK compliance 80 % (table 3). The following SWEBOK knowledge areas are not included in the passport of the specialty:

1. Software Requirements (Chapter 1);
2. Software Configuration Management (Chapter 6);
3. Software Engineering Professional Practice (Chapter 11);
4. Software Engineering Economics (Chapter 12);
5. Engineering Foundations (Chapter 15).

The passport of the specialty 08.00.05 “Economics and Management of National Economy” includes the following professional competencies, covered by the chapters of SWEBOK.

1. Development of the methodology, economic theory, and management methods in the field of communication and information is reflected in chapter 12 Software Engineering Economics and partly in Chapter 7 Software Engineering Management.
2. Economic analysis of the activities of enterprises and organizations of communication and information, carried out at the level of the industry and individual structural units, as well as in the territorial (regional) section - chapter 12 Software Engineering Economics.
3. The study of the influence of communication and informatization on the development of markets, productive forces, the efficiency of social production, socioeconomic progress and economic security of the country is reflected in the chapter 12 Software Engineering Economics.

4. Assessment of the quality of servicing the economy and the population of the country by means of communication and information - chapter 10 “Software Quality”.
5. Determination of economic efficiency of modernization of the material and technical base of enterprises and organizations of communication and information - chapter 12 Software Engineering Economics.
6. Study of the economic efficiency of new forms and methods of information support using various types of communication - chapter 12 Software Engineering Economics.
7. Investigation of regularities and principles of distribution of information flows over networks of different types of communication at the country level and individual regions - chapter 13 Computing Foundations.
8. Planning and analysis of production, business and commercial activities of communication and information enterprises - Chapter 7 Software Engineering Management.
9. Organization of licensing and certification of the activities of communication and information enterprises - Engineering Foundations (15).
10. The study of the laws, relations of production, scientific principles, forms, methods and means of formation of information infrastructure - chapter 8 Software Engineering Process.
11. Research of financial and organizational methods and mechanisms of management of innovative development of communication and information facilities - Chapter 7 Software Engineering Management.
12. Problems of improving information security and sustainable development of the communications and information technology market - chapter 13 Computing Foundations.
13. Development of the methodology for auditing information systems, including the development of guidelines, organizational, methodological and regulatory documents, methods for justifying the choice of hardware and software, procedures for managing the development process, methods for assessing risks and measures to minimize the consequences of their occurrence - Software Engineering Management (Chapter 7), Software Engineering Process (Chapter 8), Software Engineering Economics (Chapter 12).
14. Development of new information technologies that ensure efficient functioning of electronic business - Computing Foundations (Chapter 13), and partly in chapter 12 Software Engineering Economics.

The passport of the specialty 08.00.05 “Economics and Management of National Economy” covers the following chapters of SWEBOK (table 4).

The analysis showed that the passport of specialty 08.00.05 “Economics and Management of National Economy” corresponds to SWEBOK by 40 %. The following competences are not reflected in the passport of specialty 08.00.05:

1. Software Requirements (Chapter 1);
2. Software Design (Chapter 2);
3. Software Construction (Chapter 3);

Table 4. Compliance of the FSES for 08.00.05 postgraduate specialty with the chapters of SWEBOK

Chapter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Competence	-	-	-	-	-	-	+	+	-	+	-	+	+	-	+

4. Software Testing (Chapter 4);
5. Software Maintenance (Chapter 5);
6. Software Configuration Management (Chapter 6);
7. Software Engineering Models and Methods (Chapter 9);
8. Software Engineering Professional Practice (Chapter 11);
9. Mathematical Foundations (Chapter 14).

So, on the whole, it turns out that the total coverage of SWEBOK in postgraduate study in Russia is 80 %. The following chapters of SWEBOK are not included in the passports of specialties for graduate students:

1. Software Requirements (Chapter 1);
2. Software Configuration Management (Chapter 6);
3. Software Engineering Professional Practice (Chapter 11).

6 Conclusions

An analysis of the FSES for Software Engineering for bachelors and masters has shown that the aggregate requirements of both standards do not in any way cover Engineering Foundations and Software Configuration Management. This means that to obtain a master's degree in software engineering in Russia, the graduate does not need to have knowledge of these two topics, since they are not included in the list of mandatory requirements for the implementation of the educational program formed within this standard and can be included in the curriculum only at the discretion of the head of the educational program and university.

The review of passports of specialties on the postgraduate study has shown that in Russia there are adjacent specialties on which it is possible to defend the master's thesis in many fields of research related to software engineering. But, unfortunately, there are three areas of research, such as Software Requirements, Software Configuration Management and Software Engineering Professional Practice, which are not reflected in the list of areas of research adjacent to software engineering specialties. This means that today in Russia to defend a Ph.D. thesis on these areas of research is not possible.

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