Using SEFI framework for modernization of requirements system for mathematical education in Russia

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INTRODUCTION

Nowadays mathematical methods are becoming increasingly popular both in their traditional fields of application (like physics, engineering, economics) as well as in those that seems to be remote from mathematics (biology, linguistics, history, art, etc.). Mathematics widely spread into all spheres of science, and with their help it is often possible to achieve significant progress. A large number of future professionals in above-mentioned areas need serious mathematical training, which would give them an opportunity to use mathematical methods for studying a wide spectrum of problems and apply modern information technologies in the process.

Level of mathematical training is a major factor that determines success in engineering and natural sciences education, because mathematics is the fundamental discipline in these areas.

Therefore, the focus of the changing requirements for content and learning outcomes should be aimed at preserving the quality of mathematical training in respective education programs. Development of mathematical competence of a student should include the formation of a clear understanding of the requirement of mathematical component in his or her overall education, formation of correct ideas about the role and place of mathematical modelling in today's society, development of the ability to think logically, to operate with abstract objects and use mathematical concepts and symbols correctly to describe the qualitative and quantitative relationships and patterns.

To do this, the student must get the correct understanding of mathematics and mathematical models, mathematical approach to study phenomena of the real world. Learning mathematics cannot be substituted by training some of its applications and methods, without explaining the essence of mathematical concepts and not taking into account the internal logic of mathematics. Otherwise trained professional may become helpless when studying new specific phenomena, because he or she will lack necessary mathematical culture and ability to use abstract mathematical models.

In this connection there is a need for good fundamental mathematical training, high-quality content selection for mathematical disciplines based on future professional activity of a student, taking into account his or her future professional goals.

1 THE ANALYSIS OF STATE STANDARDS OF THE SECOND GENERATION

Over time, requirements for the content of mathematical education change in accordance with demands of life. This leads to changes in the state education standards (SES), which are not just regulatory documents, but also a kind of state order for a certain quality and content of training.

Until 2011, the state educational standards of the second generation (SES-2) were used in higher education in Russia. They regulated the acquisition of knowledge and skills by students for all disciplines of a curriculum, including math. SES-2 had a cyclic structure:

- cycle HSD – general humanitarian and socio-economic disciplines;
- cycle NS – general mathematics and natural sciences disciplines;
- GPD cycle – general professional disciplines;
- disciplines of specialization;
- optional disciplines.

Section 4 "Requirements for the compulsory minimum content of basic educational program" has been central to the SES-2. Table 1 contains the fragment of SES-2 for bachelor program "Applied Mathematics and Computer Science" with requirements for a minimum content of mathematical disciplines.

Table 1. Requirements for the compulsory minimum content of basic educational program

Index	Name of disciplines and their main subjects	Total hours
ЕНФ	**General mathematics and natural sciences**	**2076**
ЕНФ.01	Mathematics:	**1173**
ЕНФ.01.1	Calculus: Functions of one and several variables (continuity, differential and integral calculus, extremums); functional sequences and series; Fourier series and Fourier transform, a function of a complex variable; measure and the Lebesgue integral	816
ЕНФ.01.2	Geometry and Algebra: analytical geometry; matrix theory; system of linear algebraic equations; linear spaces and operators; elements of general algebra	357
ОПДФ	**General professional disciplines**	2248
ОПД.Ф.01	Differential equations: general theory of differential equations and systems; Cauchy problem and boundary value problems; linear equations and systems; stability theory; partial differential equations of the first order.	204
ОПД.Ф.03	Probability theory and mathematical statistics: axiomatic theory of probability; random variables, their distributions and numerical characteristics; limit theorems of probability theory; random processes; point and interval estimation; statistical hypothesis testing; linear statistical models	204

According to the SES-2 for the above-mentioned education program mathematical and natural sciences make up 28.4% of the total number of hours and general professional disciplines – 30.7%. Total amount of training academic hours is 7314.

2 THE ROLE OF MATHEMATICAL COMPETENCIES IN HIGHER EDUCATION

In 1999 Education Ministers from 29 European countries signed Bologna declaration thus creating European Higher Education Area. In 2003 Russia joined Bologna Process by signing the Declaration. In 2011 Russia introduced new standards of higher education – the federal state educational standards (FSES). The purpose of the new standards was transition of Russian universities to the implementation of education programs that meet the principles of the Bologna process.

One of the main distinguishing features of the new standards is a competence-based approach. The essence of this approach is that the emphasis of the educational process is transferred from the content of education to learning outcomes, which should be transparent, i.e. understood by all stakeholders - employers, teachers and students. The learning outcomes are described by the system of competencies, which are a dynamic combination of knowledge, skills, abilities and personal qualities that a student should be able to demonstrate after completion of his or her education.

At the same time a lot of attention is paid to competencies related to mathematical training and the ability to use mathematics in real life applications. European Commission even recommended the inclusion of mathematical competence to the list of 8 key universal competences, which nowadays each person with a higher education should possess.

This competence is even more important in the field of information and communication technologies. As part of the project TUNING RUSSIA [1], the purpose of which was to ensure the technical implementation of the reform of higher education in accordance with the requirements of the Bologna process, the subject group (SAG) on ICT conducted sociological research aimed at identifying the importance of specific subject competences for graduates in ICT.

Representatives of students, teachers and graduates of some of the leading Russian universities (excluding Moscow State University and St. Petersburg State University), as well as representatives from leading Russian and international companies in the field of ICT were given a list of competencies and were asked to rate their importance for professional work and estimate the level of their formation in existing Russian system of higher education.

Universities-members of the working group interviewed 134 employers, 168 university professors, 165 graduates and 242 students from different regions of Russia. The evaluation was conducted on the four-point scale. Among others, the list included competence for a deep mathematical training "to apply and develop fundamental and interdisciplinary knowledge, including mathematical and scientific principles, numerical methods ...". Table 2 shows the results of the survey.

Table 2. Survey of importance of competence "to apply and develop fundamental and interdisciplinary knowledge, including mathematical and scientific principles, numerical methods ..."

Group of respondents	Importance	Achievement
Academics	3.46	2.62
Employers	3.09	2.75
Students	3.07	2.77
Graduates	3.09	2.7

It should be noted that teachers were the most pessimistic in assessing the level of formation of this competence. In addition, these data clearly demonstrate the need for this competence in the education process (the average level of importance), but at the same time, one can see the need to improve the mathematical training of students to meet the challenges of present days.

Table 3 demonstrates survey results for another competence "ability to abstractly think, analyse and synthesize", which is the foundation for mathematical literacy.

Table 3. Survey of importance of competence "ability to abstractly think, analyse and synthesize"

Group of respondents	Importance	Achievement
Academics	3.66	2.92
Employers	3.36	2.8
Students	3.42	3.03
Graduates	3.56	3.08

The fundamental importance of mathematical competencies for professional work in the field of ICT has been reflected in the design of Russian Sectoral Framework of qualifications and competency characteristics for Computer Science degree programs (TEMPUS project INARM [2]). In this framework labour functions were correlated with the areas of fundamental knowledge necessary for their successful acquiring. An example of such correlation is shown in Table 4.

Table 4. Correlation of labour functions and fundamental knowledge

Groups of labour functions	Labour functions	Areas of knowledge as an instrument of formation of learning outcomes (based on the CS 2014)	Knowledge modules for building education programs
A.1. Harmonization of information system (IS) and business strategies	Foresee long-term prospects for business development and determine the IS infrastructure in accordance with organizational policy	AL. Algorithms and Complexity AR. Architecture and Organization HCI. Human Computer Interaction IAS. Information Assurance and Security GV. Graphics and Visualization IM. Information Management	Fundamentals of management; fundamentals of economics; math modelling; systems analysis; optimization methods; operations research; software engineering; Cybernetics basics

Possession of fundamental mathematical knowledge (optimization methods, operations research, systems analysis, discrete mathematics, etc.) was included to the passports of all groups of labour functions of this framework as an obligatory component. For example, passport of the group of labour functions “A.1. Harmonization of IS and business strategies” includes the following knowledge:

- system analysis;
- optimization methods;
- operations research;
- forecasting methods;
- modern standards of information exchange;

- fundamentals of economics;
- basics of management;
- data bases and its analysis;
- information security and data protection;
- hardware components, tools and architectural hardware platforms;
- operating systems and computer networks;
- strategic planning and management techniques;
- methods of investment analysis;
- theory of process management;
- methods of project work plan;
- tools and methods for determining the financial and operational performance of enterprises.

3 FEDERAL STATE STANDARDS OF THE THIRD GENERATION. ADVANTAGES AND DISADVANTAGES

The system of Russian state standards of higher education which has been operating since the mid-90s, with the introduction of the federal state education standards (FSES-3) goes farther away from the rigid standardization of educational content in a given set of disciplines with fixed complexity (the state education standards SES-1, SES-2) and proceeds to the framework structure of education programs with specified conditions for their implementation and results of their mastering (FSES 3, FSES 3+ and in the future FSES 4).

With the introduction of federal state standards of third generation (FSES 3, 2011) Russian universities have become more independent in the formation of basic educational programs, in the selection of content, forms and methods of training, which allows them to compete in the market of educational services by responding to inquiries of the labour market.

Unlike SES 2 FSES-3 includes requirements for learning outcomes of educational programs in a form of universal and professional competences of graduates and introduces credit units for measuring complexity of educational work.

In Russia, the total complexity of bachelor programs in accordance with FSES 3 and 3+ is equal to 240 credit units, which is equivalent to 8640 learning hours.

The complexities of master and bachelor programs are respectively 120 and 300 credits. Like the "academic hour" "credit unit" is the unit of measurement of the complexity of educational work of a student. All international and national education systems establish equivalence relation between credits and hours. Within the framework of the transnational Tuning project for the European Higher Education Area one credit is mapped to 24-30 academic hours. For example, in Austria, one credit is 25 hours, in Belgium - 24 hours, in Germany - 30, in the Netherlands - 28, in Finland - 26 2/3 hours. The methodology recommended by the Russian Ministry of Education in 2002 establishes a correspondence of one credit unit to 36 academic hours.

Table 5 contains a fragment of the basic educational program under the FSES for "Applied Mathematics and Computer Science" with a list of training cycles, compulsory disciplines for each cycle, complexity of each cycle in credit units and codes for competences that are forms by corresponding subjects.

Table 5. Fragment of the basic educational program under the FSES for "Applied Mathematics and Computer Science"

Training cycle code	Training cycles and planned learning outcomes	Complexity (credits)	The list of disciplines for development of exemplary programs
Б.2	Natural sciences cycle Basic part As a result of study of the basic part of the cycle the student should: have a basic knowledge in the field of applied mathematics, theoretical mechanics, numerical methods; be able to use approximate methods for solving classical problems of mathematics and mechanics; possess skills of practical use of computer programming.	40–50 14–18	Numerical methods Theoretical mechanics
	Variable part (knowledge and skills are determined by institution)		
Б.3	Professional cycle Basic (general professional) part As a result of study of the basic part of the cycle the student should: have a basic knowledge in basic mathematics and computer science; be able to formulate and prove theorems, independently solve classic problems of mathematics; possess skills of practical use of mathematical methods in the analysis of various problems	140–150 90–100	Calculus Fundamental and computer algebra Analytic geometry Differential geometry and topology Computer geometry and geometric modelling Stochastic analysis Discrete mathematics, Mathematical logic and its applications in computer science Differential equations Fundamentals of Computer Science (mathematical modelling, databases, operating systems)

Table 6 shows as an example the proportion of the disciplines of natural sciences and general professional cycles in two fundamental bachelor education programs in Russian universities according to the FSES 3.

Table 6. Volumes of natural science and general professional cycles

	«Applied Mathematics and Computer Science»	«Mathematics and Computer Science»
Natural sciences cycle	27–31.25%	16.7–20.83%
General professional cycle	45.8–50%	58.3–62.5%

According to the standards FSES 3 and FSES 3+ developers of basic educational programs are free to determine the complexity of cycles and corresponding disciplines. Table 7 shows as an example the complexity of the discipline "Calculus" in the program "Applied Mathematics and Computer Science" in three Russian universities [3].

Table 7. Number of credits for the discipline "Calculus"

University	Discipline	Complexity (credit units)
University #1	Calculus	18
University #2		20
University #3		21

The task for most universities is not unification, but harmonization of educational programs (tuning in to each other). In this regard, Russian state educational standards are undergoing significant changes and rethinking.

At the same time the following flaws of FSES revealed itself:

- sets of common cultural competences are not unified in number and are significantly different even for the related fields of training;
- sets of professional competences in most standards are excessive and poorly structured by type of professional activity of graduates (from 30 to 80 competencies in bachelor programs), "core" part of training is not specified;
- learning outcomes of individual courses of an education program weakly correlate with a set of competences defined in its standard;
- cyclic structure of basic educational programs and volume of credit units (FSES) do not allow universities to design modular (vertical) structure of education programs (European system of accumulation and transfer of academic credits, Guide ECTS [4]).

These gaps were mostly eliminated in updated standards FSES 3+ (2014):

- the requirement of cyclic structure was removed;
- "core" and "elective" parts of an educational program were defined: "core" part provides general professional and cultural training; "elective" part provides specialization that depends on a program;
- requirements for the amount of credits for "base" and "elective" parts were defined;
- an attempt to unify general cultural competences on different levels of education was made, and as a result a set of universal cultural competences was established for all programs on each level of education (for bachelor – 9 and for master programs – 3);
- in each education program the "core" of general professional competences was highlighted, other professional competences remained clearly separated for different types of professional activity;

- educational organizations now select one or more key professional activities for education programs during their development.

At the same time the introduction of new educational standards was accompanied by certain costs that included the quality of mathematical education. The transition to a two-tier system of education has led to the inevitable reduction of hours devoted to mathematics. Such reduction reaches up to 50% for various engineering programs compared to the same requirements of state educational standards.

For example, SES-2 for technical areas of education (including the field of applied computer science) gave about 800 hours for basic disciplines of mathematical cycle, of which up to 500 hours were dedicated to classroom training. The basic educational programs for third-generation standards draw a different picture, for example, Bachelor of Applied Computer Science program provides 18 credits (648 hours) for mathematics, of which not more than 59% is dedicated to classroom training. This is also evident from a comparison of Tables 1 and 7. As shown in Table 1 for SES-2, the amount of hours for the discipline "Calculus" in "Applied Mathematics and Computer Science" program in all institutions of higher education must be 816 hours, which corresponds to more than 22 credit units. According to Table 6, basic educational program made on the basis of FSES gives this discipline 1 to 4 credits less.

FSES standards and competencies system defined by them have a framework nature. Formulations of competencies are vague and difficult to verify. Therefore, without the use of maps of competences that help to reveal their content these competencies are transformed into abstract declarations with very broad and conflicting interpretations. Because of the re-orientation of educational process on the formation of competencies the system of didactic units that existed before and strictly regulated content of disciplines was lost (see. Table 1). This allows unscrupulous participants of the educational process unreasonably reduce the program of mathematical disciplines and requirements for their mastering.

Thus, the use of existing FSES is impossible without the development of competencies cards, without filling competencies with specific content that correlates with educational material of specific disciplines.

It is clear that educational programs should be provided with appropriate assessment tools, which would allow to evaluate the extent and the level of formation of stated competences. Competence must be verifiable and easily demonstrated after training. But because of the above-mentioned reasons development of adequate means of measuring the degree of development of competencies is a difficult problem at the present time in Russian universities.

Order of the Ministry of Education and Science of the Russian Federation №1367 from 12.19.2013 (the edition of 15.01.2015) addresses partly these problems. It requires creation of assessment funds for interim assessment of students and the final certification, which include:

- list of competencies as well as indication of stages of their mastering;
- description and criteria of assessment of competencies at different stages of their formation, a description of assessment scales;
- generic control tasks, or other materials necessary for the assessment of knowledge, skills and (or) experience that characterize the stages of formation of competences in the process of mastering the education program;
- instructional materials, defining the procedures for assessment of knowledge, skills and (or) experience activities that characterize the stages of formation of competences.

Thus, for each learning outcome organization determines indicators and criteria for evaluation of formation of competences at different stages, scale and estimation procedure.

SEFI Framework seems to be very helpful in the context of introduction of new educational standards, developing corresponding maps of competences and creation of assessment funds. It establishes a framework of qualifications for the curriculum of mathematical disciplines, describes learning levels and objectives, contains description of learning outcomes, and is aimed at the formation of mathematical competence in graduates of bachelor programs. The levels represent hierarchical process of learning mathematics for engineering education areas. Thus, this document serves as some interstate analogue of educational standard, but only in the field of mathematics.

It should be noted that mathematical competence in the European understanding is concrete: it is a very specific knowledge or skill, such as «the ability to multiply algebraic expressions with parenthesis». Consequently, one can easily control the formation of sufficient competences with the help of simple tasks. On the contrary, national FSES competence is a set of some general and usually quite vague requirements. One of the examples of such competences is «ability to use basic knowledge of natural sciences, mathematics and computer science, basic facts, concepts and principles of theories related to applied mathematics and computer science». Vagueness of formulations leads to the fact that such requirements are difficult to control and have therefore mostly declarative character [5].

For Russian universities there is a need for qualitative content selection for mathematical disciplines which would take into account types of professional activity of a student and his future professional tasks. It is necessary to carry out the modernization of the Russian education system in line with international trends and taking into account the educational and cultural traditions of Russia, as well as the needs of business and industry.

Methodical recommendations of the Ministry of Education and Science of the Russian Federation are targeting educational institutions to take into account requirements of the relevant professional standards while creating basic educational programs. Professional standard is a description of skills of an employee required for a certain type of professional activity. Professional competences of graduates with a focus on generalized labour functions (professional activities), given by specific professional standards, should become the basis of education standards.

4 APPROACHES TO IMPROVING MATHEMATICS EDUCATION

Lobachevsky State University of Nizhni Novgorod in the framework of TEMPUS project MetaMath developed maps of mathematical competencies, carried out modernization of programs for mathematical disciplines and created adequate funds of assessment tools in the field of ICT [6]. Competence map contains a description of a set of indicators that show the specific quality aspects of mastering the competence. Levels of mastering were determined. At each level of the quantitative degree of mastering each indicator was characterized by descriptors. SEFI framework was used actively in the process [7].

Let us consider for example the section of competence map PC3 "The ability to understand and apply in research and applied activities modern mathematical apparatus and the basic laws of science" in preparation of bachelors in the program "Fundamental science and information technologies" [8,9].

Table 8. Fragment of competence card

Indicators	Descriptors				
To know the concept: converging and diverging sequences; continuity of the function; differentiability; smoothness; derivative	lack of knowledge of the material	presence of major errors in the knowledge of basic material	knowledge of basic material with a number of minor errors	knowledge of basic material with a number of notable errors	knowledge of basic material without errors
To be able to: find limits of sequences; find derivatives of complex functions; differentiate inverse functions; differentiate functions defined implicitly; differentiate functions defined parametrically	no ability to solve standard problems	major errors in solving standard tasks	ability to solve standard problems with minor errors	ability to solve all standard problems with minor errors	ability to solve standard and non-standard tasks
To know a variety of methods and ways of calculating limits, methods of differential calculus	lack of skills	lack of a number of important skills	presence of the minimum required skills	presence of most of the basic skills, demonstrated in standard situations	presence of all the skills demonstrated in standard and non-standard situations

The fragment given in the Table 8 belongs to the first level of mastering – "technology literacy", which corresponds to the first and second year of bachelor program and also corresponds to the first level of SEFI Framework. This fragment contains only material from "Calculus". Groups of competence indicators consist of knowledge, skills and abilities that correspond to the understanding of a competence as a dynamic entity that unites them.

At the same time formulations of indicator were given in accordance with the first level of SEFI requirements, relating to calculus (differential calculus). Let us show as an example the corresponding SEFI formulations:

Sequences

As a result of studying this material you should be able to

- understand the convergence and divergence of the sequence.

Differentiation

As a result of studying this material you should be able to

- understand the definition of continuity and smoothness;
- differentiate inverse functions;
- differentiate functions defined implicitly;
- differentiate functions defined parametrically.

Five descriptors correspond to a five-point rating scale.

E-assessment tests are constructed very easily basing of this card. Here is an example of such a test for the first indicator.

The formulation of the question:

The number a is the limit of the sequence a_n, if

Possible answers:

1. $\exists \varepsilon > 0: \quad \forall N \quad \forall n > N \quad |a_n - a| < \varepsilon$,
2. $\forall \varepsilon > 0 \quad \exists N(\varepsilon): \forall n > N \; |a_n - a| < \varepsilon$,
3. $\exists \varepsilon > 0: \quad \forall N \quad \exists n > N: \quad |a_n - a| < \varepsilon$,
4. $\forall N > 0 \quad \exists \varepsilon > 0: \quad \forall n > N \quad |a_n - a| < \varepsilon$.

Thus, SEFI standard is a useful and effective tool that allows adaptation of mathematical education in the Russian state educational standards to international requirements.

Another approach to the modernization of higher education has been undertaken in the framework of the project "Scientific and methodological support for the development of exemplary basic professional educational programs for different fields of education" in which working groups from Tver State University developed exemplary basic educational programs aimed at the formation of general and universal competences for combined groups of education programs.

Work [10] describes the development of an exemplary basic educational program for group 02.00.00 "Computer and Information Sciences" of field "Math and Natural Sciences" prepared by the project participants. There are 6 education programs in this group (with consideration of bachelor and master levels), namely:

- Mathematics and Computer Science;
- Fundamental Computer Science and Information Technology;
- Software and Administration of Information Systems.

Analysis of general professional competencies of bachelor and master education programs of group 02 allowed to form a list of optimized general professional competencies taking into account the specifics of the area and the need to preserve the mathematical competence of graduates. An analysis of professional standards was conducted with the goal to verify compliance of optimized general professional competences with generalized labour functions and labour functions, related to the professional activities of graduates of corresponding education programs [10, 11].

It should be noted that generalized and ordinary labour functions do not explicitly include a list of mathematical knowledge required for their implementation. Therefore, during the analysis a list of required mathematical knowledge and skills was explicitly formulated. As a result, an exemplary set of disciplines of mathematical cycle with the division into stages of their mastering and description of assessment criteria was created on the basis of the list. According to FSES 3+ curriculum consists of three units:

- Unit 1. Disciplines (modules).
- Unit 2. Practice.
- Unit 3. State final exam.

Disciplines from the core part of the unit 1 are mandatory for students, regardless of the program.

The following modular structure has been proposed by developers for the core part of the unit 1:

- Module 1: Disciplines that form common cultural competences;
- Module 2: Disciplines that form basic mathematical literacy (math module);
- Module 3: Disciplines that form competency in computer science and information and communication technology ("ICT and Computer Science" module).

Analysis of the above-mentioned professional standards, generalized labour functions and labour functions, as well as necessary skills and knowledge, showed the need for the introduction in module 2 of such disciplines as "Theory of Probability and Mathematical Statistics", "Methods of Optimization and Operations Research” which in turn require "Calculus" and "Algebra and Geometry". It seems necessary to include such disciplines as "Databases", "Programming Methods," "Programming Languages and Translation Methods", "Software Engineering" in module 3, which in turn require "Discrete Mathematics", "Theory of Automata and Formal Languages", "Mathematical Logic and Theory of Algorithms" in module 2 and "Theoretical Foundations of Computer Science" in module 3 [10].

Paper [10] describes the development of components that make up exemplary educational program for bachelors:

- a basic exemplary curriculum that establishes the relationship of the results of development of general-purpose and professional competencies throughout the training period;
- approximate calendar training schedule;
- recommendations of developers for the content selection for educational modules;
- guidance on the content, forms and methods of carrying out intermediate and final assessments, funds of assessment tools for testing universal and optimized general professional competences.

Specialist after graduation must have a certain set of standardized professional competences, the list of which should reflect the real needs of the labour market of different countries. To ensure high quality of IT-specialists modern universities must implement specialized courses and programs for continuous education in the field of IT, based on the specific requirements of future employers – the leading IT-companies [12]. In [13], a block approach is proposed for the construction of educational programs in the field of information technology as a mean of improving the adaptability of graduates to the challenges and demands of modern life.

5 SUMMARY AND ACKNOWLEDGMENTS

Russian education standards have come a long way from being extremely detailed and regulating the content of education programs at all levels to the current state when there is a great freedom for universities in defining its education programs. Requirements for the content for training are reflected in competences which graduates of the corresponding education program should possess. The downside of that freedom is too general formulations of these competences and absence of framework requirements for the scope and content of individual parts of educational programs for the various types of training. This gives rise to the problem of preserving the unity of educational space in Russia and the traditionally high level of teaching mathematics in Russian universities. Russian scientific and educational community together with industry and business are currently looking for the ways to solve this problem.

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