School Subject Informatics (Computer Science) in Russia: Educational Relevant Areas

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This article deals with some aspects of studying Informatics in Russian schools. Those aspects are part of the 'third dimension' of the Darmstadt model (they are also projected on the other two dimensions of this model) and include evolution of the subject, regulatory norms conforming to the Federal Educational Standards, the learning objectives, the required learning outcomes, and the Unified National Examination in Informatics, which is required for admission to a number of university programs. It is interesting to note that correspondence between requirements for the outcomes of learning Informatics in Russian school and the requirements of K-12 Computer Science Standards (USA) is quite satisfactory. It is noteworthy that the relatively high level of school education in Informatics in Russia is determined by the well-established methodological system with a 30-year history, the subject's being on the list of core disciplines at school, as well as the existence of a state-sponsored system of education teachers of Informatics.

Categories and Subject Descriptors: K.3.2 [**Computers and Education**]: Computer and Information Science Education—*Computer science education*

General Terms: Algorithms, Languages, Security

Additional Key Words and Phrases: History of Informatics in school, education policies, educational standards, qualification and professional experience of teachers, learning objectives and outcomes, structural components of Informatics, curriculum issues, Unified National Exam, extracurricular activities, textbooks, didactic software

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1. INTRODUCTION: HISTORY AND POLITICS

In this article we focus on several aspects of secondary school education in Russia which relate to the school subject "Informatics." (Without going into the intricacies of terminology, within this article, we will assume that the term "Informatics" encompasses fundamental and technological aspects, and is equivalent to the term Computer Science.) These aspects are part of the so-called 3rd dimension of the Darmstadt model [Hubwieser 2013]; they are also projected on the other two dimensions of this model.

The subject "Foundations of Informatics" was introduced in grades 9–10 of all schools in the Soviet Union in 1985. The declared aim was to form "an algorithmic thinking and computer literacy" of students. The following components were identified:

(1) the concept of the algorithm and its properties, means and methods of describing algorithms, the program as a form of representation of the algorithm for computers;

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(2) foundations of programming in a programming language;
(3) practical skills with computers;
(4) principles of computer functionality and its basic elements;
(5) computer applications, their role in different sectors of human activity.

An important element in the introduction of Informatics as a school subject was teachers' preparation. A campaign to prepare teachers of Mathematics and Physics to teach Informatics at school was carried out in 1985–86. The campaign involved thousands of teachers all over the country.

A new stage of the school subject "Informatics" began in the 1990s. (Henceforth, we will speak only about Russia, not about other countries of the former USSR.) The dominant question then was: "What is the mission of the subject in general education?" For the first time in many decades, teachers in Russian schools had an opportunity to choose among different syllabi and textbooks. Three versions of the course dominated in the early nineties. Each course, covering many common topics, had its own leading line: the algorithmic line, the line of computer modeling, the line of logical thinking supported by the study of the elements of logics. Each of these three courses used programming as a basis for practice. During this period, the core subject "Informatics" was moved from high school to middle school. With the spread of personal computers and the development of application software, the paradigm of computer literacy changed. There was a partial transition from programming to operating a PC as a user.

The educational content is determined by the Federal Educational Standards (FES). These include requirements for:

(1) the structure of educational programs (including the ratio of the mandatory part of an educational program to that formed by an educational institution) and their volume;
(2) the conditions for the implementation of educational programs, including those related to personnel, finances, and logistics, among others;
(3) the expected learning outcomes in the educational programs.

Educational programs are independently developed and approved by the institution carrying out education.

In 2010–2012, a new generation of FES was introduced. According to this document, each school was given even greater opportunities to expand the scope of the educational content beyond the obligatory minimum specified by the FES. Informatics is now a compulsory subject in middle school, and any school may choose to include it in their high school curriculum at a basic or advanced level. In elementary school, elements of Informatics are taught within the core subjects "Mathematics" and "Technology." Furthermore, each elementary school has the right to make subject "Informatics" part of its curriculum.

It is important to note that the FES sets the requirements for learning outcomes in a very general form. This allows creating a variety of versions of the Informatics course, reflected in textbooks and other teaching and methodological materials. Textbooks intended for wide use in schools must pass very strict certification, confirming their compliance to the FES requirements.

Upon completion of the secondary school, students take the Unified National Examinations, on which admission to universities is based. The examinations in the Russian Language and Mathematics are compulsory, and the rest are optional. A individual's choice of examinations to take is usually determined by his/her desire to enter to a particular university program.

The current situation is presented in Figure 1.

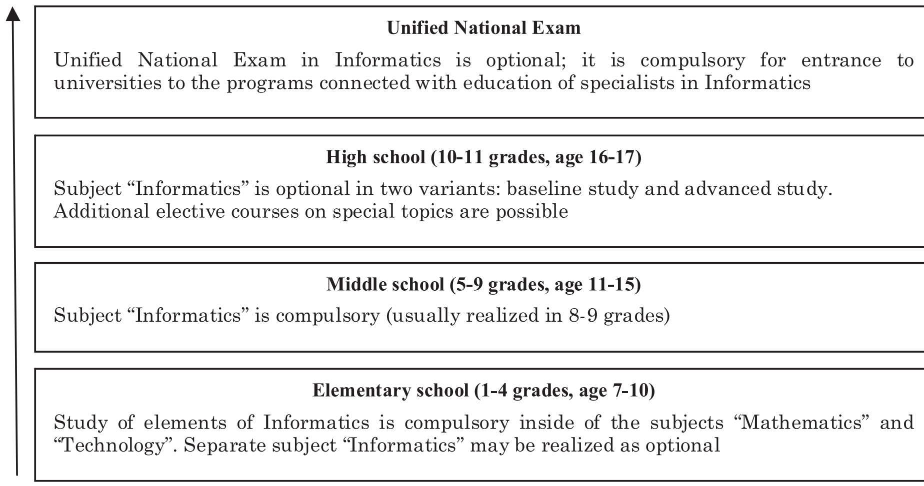

Fig. 1. Contemporary state of the subject "Informatics" in Russian school education.

In middle school, Informatics is generally studied by everyone. In high school, by our estimation based on many years of teaching Informatics and creating textbooks and manuals (reliable statistical data does not exist), about 50% of students study Informatics at the basic level and about 10% at the advanced level. The latter is confirmed by the number of students who opt for the Unified National Exam in Informatics (7.8% of all high school graduates in 2012).

There are hundreds of books and articles on the contemporary state of Informatics as a school subject in Russia, however almost all of them are in Russian [Lapchik et al. 2008], a book to which the authors of this article contributed, gives a very detailed description of Informatics as a subject in Russian schools, along with the history, objectives, content and methods of teaching. The book also contains an extensive bibliography on the topic.

2. LEARNING OBJECTIVES AND OUTCOMES

The FES determine the learning objectives for school subjects. With specific learning objectives defined individually for each subject, education as a whole is presented as a system of personal and metasubject outcomes, whereby personal development and upbringing are the overriding aims of all educational stages. In essence, it means the development of intellectual skills and formation of behavioral qualities of personal and social significance. Each school subject is expected to contribute to the achievement of both personal and metasubject results. The current required learning outcomes, listed here, are set by the FES.

Elementary school (1–4 grades) are the following:

(1) formation of the fundamentals of logical and algorithmic thinking, spatial imagination and mathematical language, skills of measurement, conversion, estimation and evaluation, data visualization and processing, writing and executing algorithms;
(2) ability to carry out verbal and written arithmetic operations with numbers and numerical expressions; to solve word problems; ability to act in accordance with an algorithm and construct a simple algorithm, to explore, identify and depict geometric shapes, work with tables, charts, graphs and diagrams, series, and aggregates; to represent, analyze and interpret data;

(3) acquisition of the initial idea of computer literacy;
(4) acquisition of preliminary knowledge of the rules of creating objects in an information environment, and skills to use them in educational activities and in visual arts.

Middle school (5–9 grades) are as follows:

(1) formation of an information and algorithmic culture, of the concept of a computer as an instrument for multi-purpose information processing; development of basic skills of operating computer equipment;
(2) formation of the basic concepts: information, algorithm, model, and their properties;
(3) development of an algorithmic thinking necessary for professional work in modern society, development of an ability to make and write an algorithm for a particular executor, formation of knowledge of algorithmic structures, logical values and operations, familiarity with one of the programming languages and with basic algorithmic structures: linear, branched and loop;
(4) formation of the skills of formalization and structuring of information, ability to choose how to present data in accordance with the task—tables, charts, graphs, diagrams—using appropriate data software;
(5) formation of the skills of safe behavior when working with computer programs and the Internet, ability to observe the norms of information ethics and law.

High school (10–11 grades), basic level, are the following:

(1) formation of the concepts of the roles of information and related processes;
(2) ability to use algorithmic thinking skills and understand the formal description of algorithms;
(3) ability to understand programs written in a selected algorithmic language, knowledge of basic programming constructs, an ability to analyze step-by-step execution of algorithms;
(4) use of standard methods of creating programs in an algorithmic language using standard basic designs for programming and debugging such programs; use of ready-made computer applications;
(5) formation of the concept of computer and mathematical models, and ability to analyze the model and the simulated object (process);
(6) formation of the concept of databases and ability to work with them;
(7) ability to use methods of data presentation and analysis;
(8) formation of basic skills and knowledge about safety and hygiene, when working with the computer,
(9) knowledge of basic concepts of legal aspects of computer programs and the Internet use.

High school (10–11 grades), advanced study, additional requirements, are as follows:

(1) acquiring basic knowledge of the contribution of Computer Science to the formation of the modern scientific world;
(2) acquiring knowledge of basic algorithms for processing numerical and textual information, and algorithms for searching and sorting;
(3) a command of universal high-level languages (optional), basic concepts of data types and data structures, and an ability to use the basic algorithmic structures;
(4) skills and experience in software development in the chosen programming environment, including testing and debugging programs; basic skills applied to problem formalization and documentation of programs;

(5) creation of digital objects, their properties, algorithms for their analysis, data coding and decoding, identification of the reasons of data loss or distortion in transmission, systematization of knowledge related to mathematical objects of Informatics, ability to construct mathematical objects, including logical formulas;
(6) formation of the concept of the structure of modern computers; trends of computer technologies development; basic functions of operating systems; creation and operation of Internet applications;
(7) formation of the concepts of computer networks and their role in the modern world; knowledge of the basic principles of organization and operation of computer networks, information ethics and rules of law, principles of information security, ways and means to ensure reliable operation of ICT tools;
(8) basic knowledge of databases, their structure and means of creating and working with them;
(9) ability to build and to use computer mathematical models, carry out experiments and process statistics by the computer, to interpret results obtained during simulation of real processes; ability to evaluate numerical parameters of simulated objects and processes using databases and archives;
(10) formation of an ability to work with program libraries, experience in the use of computer-assisted data presentation and analysis.

As mentioned earlier, the education and personal development of students in Informatics focus on the development of certain forms of thinking and on the formation of intellectual skills, as well as on fostering certain personal and social behavioral characteristics. We have formulated the components of students' personal development and upbringing which must be fulfilled in the process of studying Informatics.

— Development of algorithmic thinking
— Development of systems thinking
— Forming the skills of formalization and systematization
— Forming communication and presentation skills (ability to perceive other people's opinions, and choose appropriate forms of communication, a transparent presentation of ideas and results, an experience in creating group projects)
— Forming the skill of accessing ICT tools to solve problems
— Forming the skill of rational search in the information space
— Forming the skills of information security, legal and ethical behavior in the field of information activities
— Forming the skills of self-development, self-study, self-organization, and self-appraisal
— Forming a holistic scientific view of the world and of the place of Informatics in it

This list corresponds to the requirements for personal and meta-subject outcomes of general education set by the FES.

3. THE STRUCTURAL COMPONENTS OF THE INFORMATICS COURSE

The authors have identified some structural components within the Russian school course of Informatics. We have also explored the relative weight of each component in the course based on the textbooks which we have co-authored and which are widely used across Russia.

Middle school (105 academic hours in the curriculum, academic hour = 45 minutes). The ratio between the "weights" of the structural components in middle school is shown in Figure 2. The weight is determined as the average of two values: the number of hours in the curriculum and the amount of text in the textbook.

1. Theoretical foundations
2. Principles of computer's functioning
3. Information technologies
4. Network technologies
5. Algorithmization
6. Languages and methods of programming
7. Modeling
8. Informatics and society

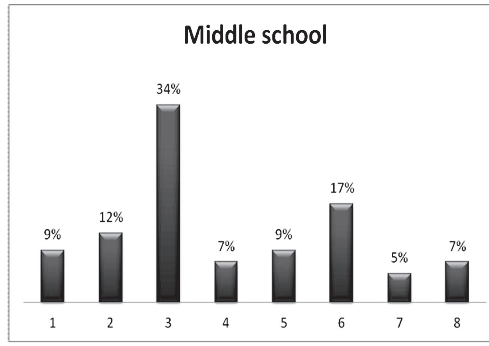

Fig. 2. Relationship between the structural components of the Informatics course in middle school.

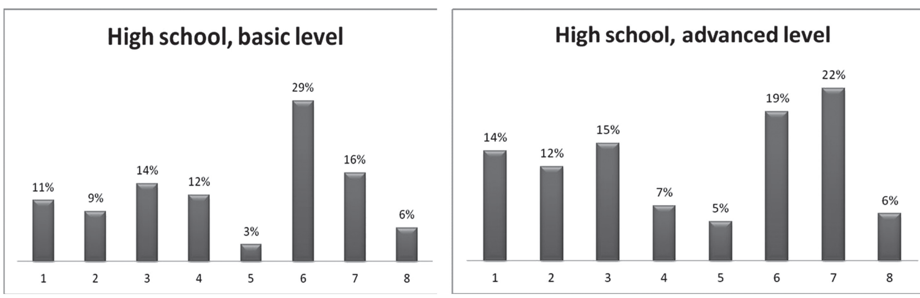

Fig. 3. Relationship between the structural components of the course of Informatics in high school.

The IT component of the Informatics dominates at this level of education (41% of the course). This is explained not only by the need to achieve specific results, but also by the need to develop a general information and communication competence in students. Algorithmization and programming together account for 26% of the course. This allows teaching the basic concepts in this area. Modeling is studied only on a conceptual level, and the application of computers to the real world by means of modeling is mainly reserved to high school.

In *high school*, the study of Informatics is carried out at one of the two levels: basic (10 academic hours in the curriculum) and advanced (280 academic hours in the curriculum). Appropriate ratios between the "weights" of the structural components, are shown in Figure 3.

4. COMPLIANCE TO THE STANDARD K-12 (USA)

An interesting insight is gained by comparing the required outcomes of Informatics study in Russia to those in other countries. We give an assessment of the degree of correspondence of the requirements in Russia to those found in the K-12 Computer Science Standards, developed by the Computer Science Teacher Association, USA [K-12 Computer Science Standards. Revised 2011].

The assessment was made using a three-tier system: the requirements are not in compliance, partially in compliance, and fully in compliance with K-12 CSS. The article size limitations do not allow us to describe these assessments for each of the multiple requirements of K-12 CSS, therefore we will restrict ourselves to a summary.

K-12 CSS singles out 5 strands of school education in Informatics. Our analysis has shown that all the 69 requirements for learning outcomes in Informatics in middle school, set forth in K-12 CSS, have analogues in the Russian FES.

Table I. Correspondence between Requirements for the Outcomes of Learning Informatics in High School (Russia) and the Requirements of K-12 CSS (USS)

Strand	Number of requirements in K-12 CSS	Full compliance	Partial compliance	Not in compliance
Computational Thinking	11	0/7	7/3	4/1
Collaboration	4	0/0	3/3	1/1
Computing Practice and Programming	12	0/5	8/7	4/0
Computer and Communications Devices	10	0/5	6/5	4/0
Community, Global, and Ethical Impacts	11	1/6	8/5	2/0
In total	**48**	**1/23**	**32/23**	**15/2**

For high school, K-12 CSS recommends studying Computer Science in its three versions:

— computer Science in the modern world (our analogue is the basic level),
— computer Science concepts and practices (our analogue is the advanced level),
— topics in Computer Science.

Table I shows the authors' estimation of the correspondence between the requirements for learning outcomes in Informatics in Russian high schools and those in K-12 CSS. The number on the left of the slash represents the basic level; the one on the right represents the advanced level.

Given the significant differences in the educational systems of Russia and the United States and the different statuses of Informatics as a school subject, the level of compliance should be considered quite high.

It is worth noting again that we have compared the actual requirements for Informatics education in Russian schools with an idealized concept of what such education should be like in the U.S. schools according the document K- 12 CSS. Our informed evaluation of secondary school education in computer science in the world suggests that the level of requirements set in that document is not fully achieved in any country.

5. TEXTBOOKS, DIDACTIC SOFTWARE, PEDAGOGICAL JOURNALS, CONFERENCES

The federal list of textbooks for the academic year 2013–2014 includes 79 textbooks in Informatics for all levels of schooling. These have been written by 19 groups of authors and published by 7 publishing houses federally licensed to produce educational literature. The textbooks on the list may be purchased with federal budget money and supplied to school libraries. Teachers have the right to choose textbooks from this list. Ten out of the 79 books have been written by the authors of this article and their co-authors.

A textbook must pass a three-step evaluation process in order to be included on the federal list. It is evaluated by the Russian Academy of Sciences, the Russian Academy of Education, and experts from the teacher community. The aim of the first step is to assess the academic level of the book. The aim of the second step is to assess its pedagogical and didactic quality. The final evaluation is conducted by teacher experts based on their practical experience using the textbook.

A wide array of didactic software, covering all the topics of school Informatics, was commissioned by the Ministry of Education and Science on a competitive basis. It has now been developed and made available on the Internet. The software is free of charge for teachers and students. Additionally, many teachers create such software themselves and make it freely accessible on the Internet.

The website of the Russian publishing house BINOM features "methodological workshops" of the leading authors of school textbooks and manuals in Informatics.

Several academic journals on methods of teaching Informatics are currently published in Russia: "Informatics and Education" (since 1986), "Pedagogical Informatics" (since 1994), "Informatics in School" (since 2002), and others. Academic and methodological conferences on teaching Informatics are regularly held. One example is the ITO (Information Technology in Education) conference, which has been held for the last 23 years. The longest-running and most well-attended workshop at that conference is in methods of teaching Informatics. In 2011, Moscow State University, the country's largest institution of higher education, hosted a convention for teachers of Informatics, which was attended by about 1,400 people. It was at that event that the social organization called "The Russian Association of Informatics Teachers" was established.

An example of the regional conference on school Informatics is "Christmas Readings", which has been held annually for more than 15 years in Perm State University. In 2014, about 200 participants from different regions of Russia took part in the conference.

6. THE UNIFIED NATIONAL EXAMINATION

The Unified National Examination (UNE)[1] in Informatics is not compulsory for all school graduates. It is necessary, first of all, for admission to Informatics-related programs at higher educational institutions. The examination is a very serious test for school leavers.

The exam tasks are grouped into 3 blocks: "Mathematical foundations of Informatics", "Algorithmization and programming", and "Information and computer technology." The testing materials consist of three parts. Part 1 is a multiple-choice test with four given options, and it covers all the blocks. Relatively little time is set aside to complete this part. Part 2 contains a set of tasks of basic, intermediate and advanced levels of complexity. These require brief answers such as a number or a sequence of characteristics. Part 3 contains a set of tasks of an even higher level of complexity than advanced. These tasks usually involve writing a detailed answer in free form. From year to year, the number of tasks in each part varies slightly. For example, in 2012, part 1 contained 13 tasks; Part 2, 15 tasks; and Part 3, 4 tasks.

The examination covers the key topics from the Informatics school syllabus. The tasks with detailed answers are the most labor intensive. These include tasks on the analysis of algorithms, drawing up computer programs, among other types. The answers are checked by the experts of regional examination boards based on standard assessment criteria.

In the past five years, approximately 60,000 students a year have registered for the UNE in Informatics. This represents about 8% of the total number of high school graduates.

The minimum pass threshold has been set at the level of 36 points out of 100. In 2010, 7.2% of the exam-takers failed to reach that level, in 2011 it was 9.8%, and in 2012 11.1%. The university programs which have the USE in Informatics as an entrance requirement establish their own thresholds for entering the competition. These are usually higher than the one mentioned earlier.

The UNE results in Informatics in urban schools are much better than in rural ones. The gender difference is very small, less than 1 point from the average mark.

[1]http://www.ege.edu.ru/(in Russian).

7. EXTRACURRICULAR ACTIVITIES

In addition to regular schools, Russia has a system of supplementary education, partially funded by the state. Institutions of supplementary education cater for children in many areas, such as creative arts, sports, science, social studies, etc. Among these, educating schoolchildren in information technologies (computer graphics, web-programming, information systems, and others) is very common and in great demand. For example, at the authors' own university, a Computer School has been operating since 1994. During this time it has trained some 5,000 schoolchildren.

A National Olympiad in Informatics has been held in Russia for many years. The participants pass through several stages: the school stage, which involves large numbers of students; the municipal, regional, and federal stages. Winners of the federal stage go on to take part in the International Olympiad in Informatics.

Russian school students have been participating in the International Olympiad in Informatics since 2000. The leadership in these competitions consistently belongs to students from China, Russia and the United States. Since the beginning of their participation, students from Russia have finished 3rd three times, 2nd three times and 1st three times in the unofficial team standings.

8. TEACHER PREPARATION

Regular education of teachers of Informatics started in 1985, the year when the subject first appeared in the school curriculum. For many teachers, Informatics has since become their main or only field of instruction.

Initially, the course lasted 5 years, and the qualification "Teacher of Informatics" was awarded to the graduates. Today, a 2-level scheme is more common. The basic education lasts 4 years (a Bachelor's program with a single specialization in Informatics) or 5 years (a Bachelor's program with a dual specialization, for example, "Mathematics and Informatics"). Some of the graduates go on to enroll in Master's programs afterwards. The courses include Theoretical Informatics and Information Technology, Education, Psychology and Methods of Teaching Informatics, and many others. Additionally there is a teaching practicum.

Not all graduates go on to work at schools as teachers of Informatics. The high demand in IT specialists in Russia allows them to find jobs that are more remunerative than teaching. Those who do work at schools, however, form highly educated elite of Informatics teachers.

Many teachers with other specializations come to Informatics after having taken professional courses offered by a variety of teacher-training institutions.

Several measures to support in-service teachers have been implemented. Pedagogical institutes, universities, and special institutes of professional training for teachers regularly hold refresher courses where innovative methods of Informatics teaching are reviewed. Methodological societies of Informatics teachers function in various cities and regions.

9. CONCLUSIONS

Computer Science is now one of the key educational fields on a global level. As a school subject, it has dual nature, that is, the source of knowledge in a particular area and a source of general skills needed for life and further professional education. Obtaining such knowledge and skills is necessary for people living in any country, and it is in school that they can be obtained.

In our opinion, the system of teaching Informatics (Computer Science) in Russian schools is an important contribution that Russian education can make to the global educational system.

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