INFORMATION AND COMMUNICATION TECHNOLOGY EDUCATION BASED ON THE RUSSIAN STATE EDUCATIONAL STANDARD OF "APPLIED MATHEMATICS AND INFORMATICS"

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We strive in life so in the end
Paradise attain, to heavens ascend.
It is better our ways amend
This moment now, joyously spend.

Rubaiyat of Omar Khayyam

English translation by Shahriar Shahriari.

Introduction

In this article we will use the term Information and Communication Technologies (ICT) in its broad sense as an analogue to the term Computing, accepted in the USA. ICT field is rapidly expanding; governments and private companies invest in its development vast sums of money. New paradigms, concepts, standards, tools and application systems appear and are deployed very quickly, supplementing and/or replacing each other.

Considering this process, the authors of [1] note, that the 90th witnessed ICT specialist activities diversification, which resulted in formation of five disciplines family: Computer Engineering [2], Computer Science (CS) [3, 4], Information Systems (IS) [5], Information Technology (IT) [6] and Software Engineering (SE) [7]. The authors of [1] believe that CS still deals with theoretical informatics, IS — with design of information systems, that generate, process and distribute data in an organization from the point of view of their content and business processes for competitive advantages achievement. It is also stated that SE has gradually come from CS, and IT has appeared recently for education of specialists to administer, maintain and schedule complicated network infrastructures modern organizations can't work without.

It is reasonable that this development considerably increases both importance and complexity of adequate curricula models development and deployment problem to accomplish the task of educating the specialists, capable of long-term efficient professional activity in ICT (Task). This problem is constantly the focus of attention for ICT communities in the USA [1–7], and scientists, teaching strategy unions of Ministry of Education and Science, and industrial associations in Russia [9–21], as well.

In [1] it is proposed to have separate curricular guidelines of undergraduate programs for each of the five disciplines. We do not consider the CE discipline in this article. The purpose of the article is to show that it is possible (and expedient) to organize efficient education of specialist for the four remaining disciplines in the framework of Russian state educational standards family "Applied Mathematics and Informatics", mainly on the basis of Bachelor direction 010500 ("old" cipher 510200), following (if necessary) by a specialization.

1. Motivation to use standards family "Applied Mathematics and Informatics"

New disciplines curricular guidelines development is an important task undoubtedly. At the same time, institutions of higher education possess much inertia and new guidelines introduction and stabilization speed they can provide is considerably lower than the speed of changes in ICT viewed nowadays [1, 22]. On the other hand it is necessary right now to respond to ICT diversification. In Russia there are for a long time SE standard – 220400 "Computer Engineering and Computer-Based Systems Software" (Specialist) and IT standard – 654700 "Information Systems" (Bachelor of Science, Specialist, Master of Science). Considerable growth of need for ICT specialists is expected in Russia, by some forecasts [23] — 40 000 for the 5 on-coming years. Under existing conditions one of the sensible reactions aimed at the Task accomplishment is the adjustment of the existing standards (curricular guidelines) that are widely spread in the Universities.

One of the important ICT curricular guidelines requirements is their flexibility which will allow to use them successfully to accomplish the Task under diversification conditions for a rather long period of time. It is natural that at the same time the standard is to contain a permanent part serving as a basis and a variable part that provides reaction to the changes. Forming the permanent part of the standard in Russia it is natural to rely on our current tradition to provide education fundamentals. Its essence is that student doesn't study a set of means to solve particular problems, but theories, methods and approaches, underlying these means development. Fundamentality of the qualification allows the production of a graduate of sound quality with a high probability of professional productivity. It also provides for a graduate to become a lifelong learner with a capacity of rapid adaptation to innovation in an area of specialization. Authors of [3, 4, section 9.1.6.] share the approach.

The role of Mathematics in ICT formation and development is considered to be a fundamental one, as ICT professional deals with formal, abstract concepts and objects. In [3, 4, part 9.1.1.] it is stressed: "Mathematics techniques and formal mathematical reasoning are integral to most areas of computer science. <…> Given the pervasive role of mathematics within computer science, the CS curriculum must include mathematical concepts early and often.".

More over, CS curriculum models for USA research universities include "from a one-semester course to a sequence with three or more courses " [3, 4, part 9.4.1] of Calculus (note, 010500 standard provides up to five terms). In [7] it is advised to include in SE curriculum 2 terms of Calculus and it is stated to be a common practice in the majority of universities in Northern America. The list of in-depth courses [3, 4, part 9.3.] numbers "Combinatorial Analysis", "Probability and Statistics", "Numerical Methods", "Operations Research", and some others that are obligatory in 010500 standard. In [1–7] the importance of mathematical training in five listed in [1] (and engineering by definition) ICT disciplines is also stressed. Note, precisely Applied Mathematics is meant.

It all allows sound formulating a highly important statement for what follows: Applied Mathematics methods form the basis of CS discipline. The latter one in its turn is a IS, IT and SE disciplines progenitor.

So, it is obvious that under ambiguity conditions caused by diversification it is necessary to use "reverse" approach to curricular guidelines formation, when corresponding engineering constituents are included in guidelines providing mathematical training of full value. This approach, firstly, perfectly fits the fundamentality of education and flexibility of curricular guidelines and, secondly, it allows accomplishing the Task by adjusting existing widely spread and stable university standards.

In spite of the fact the importance of graduate mathematical competence is repeatedly stated in [1–7], there is no explicit indication of the task to form exactly integral mathematical culture (MC) of the graduate that in our opinion is the most important ICT curricular guideline requirement. Let us explain this statement.

A. In [1–7] the necessity to form creative, abstract and even “on the whole mathematical” [7] thinking of the graduate is stressed. But it is this self–independent, quick, flexible, strict analytical and logical thinking that is formed in the process student mastering MC. It results in his ability to formulate and solve a great variety of complex problems that is also one of the most important ICT specialist qualification components [24, section 4.1 and its references; 3–7].

B. Basic MC is a multi-purpose tool not only for the current professional activity, but for self-education as well. Possessing it the graduate will quickly master any contemporary and coming ICT concepts, methods and technologies, that is of critical importance under rapid ICT changes observed. Note also MC possessing will enable student to master engineering ICT components quicker.

C. Forecast of ICT diversification process development is not clear (and forecast about the need for ICT specialists with higher education as well). One of the rather likely scenarios is the one where considerable simplifications of architectures and interfaces of applied, first of all administrative, systems and infrastructures will occur due to the research and development monopolization and concentration, and diversification process will be replaced by a reverse one. In that case fundamentally educated graduate, possessing MC, stands a better chance to find a job in the fields different from ICT.

D. MC is an utterly necessary basis when reproducing highest level of proficiency personnel (PhDs and Doctors of Science) — lectures, researchers and administrators, capable of innovation ideas generation and implementation, who are necessary for both higher school and industry. Note, “Bachelor – Master” scheme considerably facilitates the high-quality dissertation preparation task for post-graduate students, providing period of its preparation increase, under certain conditions, from three up to almost five years. The latter is highly important for solving increasingly relevant task of Russian higher school and science personnel potential renewal.

Further we will consider how it is possible to adjust 01050{0|1} standard family — “Applied Mathematics and Informatics” to accomplish the Task, having 13 years experience of it in PetrSU. The usage for the purpose of other similar standards lies outside the scope of this article.

2. Characterization of standards family 01050{0|1} — “Applied Mathematics and Informatics”

In Russia there exists a state educational standards family [25– 27] “Applied Mathematics and Informatics” with education in specialty 010501 (Specialists — 5 years) and in directions 010500 (Bachelors of Science — 4 years, Masters of Science — 6 years). The bachelor direction 010500 was approved by Higher School Committee at 1992, the first temporal standard version was accepted at 1993, and the following versions don’t differ from it sharply.

The standard has the following basic characteristics. The total student work content is 7 314 hours for 132 weeks of study (8 terms), or about 73 conditional term courses (CTC, approximately corresponds to 2 lecture hours + 2 hours of practical training + 2.12 hours of self-instruction per week during 16.5 weeks of one term). Standard courses fragmentation by blocks is offered below. The first digit after name of block is its time percentage of the total amount, the second one — CTC number in the block:
– Humanitarian and Socio-economic Sciences — 24 %, 17;
– Natural Sciences — 9 %, 6;
– Mathematics general — 28 %, 21;
– Applied Mathematics — 16 %, 12;
– ICT general — 12 %, 9;

– ICT according to the faculty decision / elective courses — 11 %, 8.

We have included directly relevant to ICT courses from Natural Science and general vocational training parts of the standard in ICT course blocks. The time, provided for special discipline cycle as well as for optional, regional and elective courses, we have divided into equal parts between Applied Mathematics and ICT blocks. Thus it is possible to provide about 1 700 hours in the framework of the standard to study ICT, that is equal to 17 CTC and comprises 23 % of the total student work time, which due to the permissible standard variations can be increased, if necessary up to 30 % (2 190 hours, 22 CTC).

Specialist education standard 010501 provides total 8 032 hour student work content during 9 terms, the tenth term is predefined for practical training and degree work development. Standard content and structure are in close agreement with 010500 Bachelor standard, but work content is 718 hours increased concerning the latter (approximately seven CTC). From them 10 hours belongs to national-regional component, 20 — to elective courses and 688 — specialization disciplines. It means that the fifth year of studies allows ICT study time increase up to 2 418 hours, that is equal to 24 CTC (30 % of study hours).

Master training standard 010500provides total 4 100 hour undergraduate work content during 88 weeks of study for 2 years after taking Bachelor degree. Standard flexibility provides 12 different training areas (problem fields), three of them directly relate to ICT. They are “010509. Software Design”, ”010510. Networks Software” and ”010511. System Programming”. The standard has the following courses block fragmentation:
– obligatory — 27 % (10 % - regional component);
– specialization — 20 %;
– optional — 5 %;
– research work — 27 %;
– master’s thesis — 21 %.

Thus, 73% of the study hours is intended for undergraduate mastering in the chosen specialization area.

These standards, being essentially curriculum development guidelines, are functionally analogues to [2–7] ACM guidelines and have the following important properties, enabling to accomplish the Task.
1. In the permanent part integral MC formation is provided, which is the ICT competence basis.
2. Sufficient time is provided for obligatory ICT courses.
3. Special and elective discipline range entirely enables the faculties to reflect current ICT changes in curricula.
4. Standard adjustment to the Task accomplishment can be implemented not by means of new standard approbation and acceptance, but due to the new specialization creation, that is essentially less complex from the procedural point of view.
5. The standard has proved itself well in Russia. In [10, 11] it is stated that trained on its basis graduates, working in ICT, possess high professional skills.

Let us examine a question whether 010500 Bachelor standard has enough study hours to accommodate Core subjects of CS, IS, IT and SE disciplines Bodies of Knowledge (BK) specified in [3–8].

3. Comparative temporal characteristics of Bodies of Knowledge Cores

We have conducted a comparative research on study hours, provided for BK Cores of IS [5], IT [6] and SE [7] disciplines concerning CS BK Core [3, 4]. In Table 1 the common Cores part is shown, and in Table 2 — special IT and SE Cores parts, not included in CS Core. Special IS Core part is described below. In “Area” columns of the table 1 the CS subject names are given in full, and for IT and SE their character designations are offered from [6] and [7] correspondingly. These designations are not given in [5], that is why we have introduced our own ones, which consist of specified in [8] second level part numbers, letter abbreviations of part names and low level part numbers in brackets. Table 1 lines contain subjects and corresponding number of hours that according to our expert evaluation are common for Cores.

Lecture hour number for CS [3, 4], IT [6] and SE [7] is given in “h” columns. For IS the total Core lecture extent in [5] is defined as 10 courses by 48 hours per term, the number of lectures per distinct subjects is not given, and we obtained it on the expert evaluation of the subject description proximity basis from the detailing [5] document [8]. For all four disciplines the total number of study hours is specified in [3–7] as lecture time multiplied by four. To approach CS temporal characteristics to SE we have added 2 hours to PL Area, 1 hour to SE.1 unit, 1 hour to SE.4. unit and 2 hours to SE.6. unit of CS in “h” column, that doesn’t affect the overall picture. Mathematical Area DS is not specified explicitly in IS and IT guidelines and is included in their Core common part by us, based on general recommendations in [5, 6]. Column “Lectures in the Core” data for IS, IT and SE are taken from [5–7].

In table 2 the number of hours in brackets provided by the guidelines follows the Area name, in the “h” column — number of hours that is left after carrying a part of the hours into the common Cores part. Table 2 columns are not interrelated.

IS BK consists of three parts — Information Technology (IT), Organizational and Management Concepts (OMC) and Theory and Development of Systems (SDT). IT part is almost entirely accommodated in CS BK Core except for insignificant number of subjects. OMC part is entirely accommodated in the special IS BK part, except for the “Social and Professional Issues” subject. SDT part concerns information systems design and implementation, but it contains about 20 % of Software Engineering subjects that are included in CS BK Core.

Later on we will use “B standard” term for the phrase “010500 Bachelor standard”. This standard total study hours extent providing for ICT study we recognize as 1 920 hours and designate as B–ICT. Obtained temporal characteristics analysis shows that CS Core are almost entirely included in IS, SE and IT Cores. IT Core common Areas extent is considerably less due to the AL, PL, GV, IS, SE Areas absence and considerably less AR Area extent. It means that B standard, considering DS Area natural introduction in its general mathematics courses block, allows accommodating total study hours extent of BK Cores of each of four disciplines freely in B-ICT.

Thus we have come to the fundamental conclusion: CS Core knowledge is basic for ICT sphere in general, i.e. they are fundamental for IS, IT and SE disciplines that allows considering the latter to be applied disciplines concerning CS. This conclusion agrees well with sections of [4–7] that are devoted to IS, IT and SE Cores connections with CS Core.

Table 1. Common part of four ICT disciplines BK Cores

	Computer Science		Information systems			Information Technology		Software Engineering		
№	Area	h	Area		h	Area	h	Area		h
1	DS. Discrete Structures	43	Included by us		43	Included by us	43	FND.mf.1 – 6		43
2	PF. Programming Fundamentals	38	1.3 PL (1,3,4), 1.2 ADS (1-3,8)		38	PF	38	CMP.cf.1,3		38
3	AL. Algorithms and Complexity	31	1.2. ADS (1.2.6-7)		31		0	CMP.cf.2		31
4	AR. Architecture and Organization	36	1.1 Comp(1,3,4,6)		36	PT2	3	CMP.cf.5		26
5	OS. Operating Systems	18	1.4 OS (1-5)		18	PT1, PT3, SA1	15	CMP.cf.10		18
6	NC. Net-Centric Computing	15	1.5 Tele (1-5,7,9)		15	IAS5,NET1, WS4	16	CMP.cf.12		2
7	PL. Programming Languages	23	1.3 PL (4-7)		23		0	CMP.cf.9, cf.13, ct9		23
8	HC. Human-Computer Interaction	8	1.4 OS (10), 3.9 ISD (6)		8	HCI1, HCI4	9	DES.hci.1 - 10		8
9	GV. Graphics and Visual Computing	3	3.9 ISD(6)		3		0	в спец. областях		0
10	IS. Intelligent Systems	10	1.7 AI		10		0	в спец. областях		0
11	IM. Information Management	10	1.6 DB (1-3), 3.3 SDCM (2)		10	IM1	8	CMP.cf.11		10
12	SP. Social and Professional Issues	16	2.9 Pro (7), 2.8 LEA (1-7)		16	SP2 ,3, 5, 8,9	11	PRF.pr.1-4, 6		16
13	SE. Software Engineering	35			27		0			35
	SE1. Software design	9	3.4 SDTT	9				DES.con, ES.str	9	
	SE2. Using APIs	5		0				CMP.ct.1	5	
	SE3. Software tools and environments	3	3.2 ASD (1)	3				CMP.tl.1-5	3	
	SE4. Software processes	3	3.3 SDCM (1)	2				PRO.con	3	
	SE5. Requirements and specifications	4	3.9 ISD (7)	4				MAA.rfd.1-10	4	
	SE6. Software validation	5	3.9 ISD (7)	3				VAV.fnd	5	
	SE7. Software evolution	3	2.2 ISM (15)	3				EVO.pro.1 – 3	3	
	SE8. Software project management	3	3.10 SITS (7)	3				MGT.con.1-5.	3	
	Total lectures in common part of Cores	286			278		143			250
	Without mathematical Area DS									
	Lectures in common part of Cores	243			235		100			207
	Lectures in special parts	N/A			245		181			244
	Lectures in Core	243			480		281			451
	Study time in special parts	нет			980		724			976
	Study time in Core	972			1920		1124			1804

Table 2. Special parts of BK Cores

Information Technology		Software Engineering	
Area	h	Area	h
ITF. IT Fundamentals (33)	33	CMP. Computing Essentials (172)	17
HCI. Human Computer Interaction (20)	11	FND. Mathematical & Engineering Fundamentals (89)	46
IM. Information Management (34)	26	PRF. Professional Practice (35)	19
IAS. Information Assurance and Security (23)	21	MAA. Software Modeling & Analysis (53)	49
IPT. Integrative Programming & Technologies (23)	23	DES. Software Design (45)	28
NET. Networking (20)	9	VAV. Software Verification & Validation (42)	37
PT. Platform Technologies (14)	0	EVO. Software Evolution (10)	7
SA. Systems Administration and Maintenance (11)	7	PRO. Software Process (13)	10
SIA. System Integration & Architecture (21)	21	QUA. Software Quality (16)	16
SP. Social and Professional Issues (23)	12	MGT. Software Management (19)	15
WS. Web Systems and Technologies (21)	18		
Total	181	Total	244

Table 1 and 2 analysis allows us to draw the following conclusions on total study hours correlation, provided in B standard and in guidelines [3–7] for CS, IS, IT and SE disciplines.

A. In [3, 4] it is stated that the total CS study hours in American and Canadian universities vary greatly and its precise extent is not mentioned. When computing it assuming that the graduate is, besides Core courses, to study 12 CS courses 160 hours each all in all (except for DS subject), it gives 237 lecture hours in the special part in addition to 243 Core hours, i.e. 480 lecture hours or 1 920 study hours. It means that total CS study hours (not only BK) is entirely accommodated in B-ICT, especially if to take into account that in its mathematical blocks there provided courses, that in [3, 4, part 9.3] (see also part 1 of the article) are recommended to be included in the curriculum as advanced ones. Thus B standard can be thought to be guidelines [3, 4] equivalent in both content and CS knowledge extent.

B. The total IT study hours (1 800 lecture hours) are not only entirely accommodated in B-ICT, but they allow (if using B standard for IT training) offering recommended mathematical training [6, section 8.1.1] and advanced courses [6, section 8.2] for graduates.

C. IS Core extent is also accommodated in B-ICT. It is stated in [5] that this Core is for 2 years of study, and recommendations on total study hours extent scheduling are given in a general form: “Prerequisite or interleaved topics directly applicable to the IS curriculum therefore include: <…> discrete mathematics, introduction to calculus, introductory statistics, <…> principles of economics and functional areas of the organization such as accounting, finance, human resources, marketing, logistics <…>”

When using B standard to train IS specialists the study of mathematical courses occurs naturally, and Economic and Organization courses that are not in IS Core, can be offered at the cost of Humanitarian block time and partly Applied Mathematics block.

D.SE Core is entirely accommodated in B-ICT. And additional courses, recommended in [7] for complete curriculum introduction (“Calculus”, “Physics”, Humanitarian and Social courses), belongs also to B standard. Thus the considerable part of total SE study hours can be also accommodated in B standard.

The question about the possibility to accommodate the total study hours of IS and SE disciplines in B standard lies outside the scope of this article and requires additional research. At the same time our analysis unambiguously shows that B standard can be used for BK Cores instruction, and for the considerable part of complete curriculum knowledge of all four disciplines as well. At the same time it is possible to say with certainty that Specialist education standard 010501 (5 years of study) allows all 4 discipline graduate training in total compliance with recommendations [3–8], and 010500 Master of Science standard provides in-depth disciplines study and preparation for post-graduate school.

Standard B adjustment for four ICT discipline graduate education is to be conducted by means of its 3 professional blocks fixation: Mathematical Core, ICT Core and special blocks corresponding to each of the disciplines. Blocks content can be considered to be formed, and the task is to develop rational connections between them. From the procedure point of view CS, IS, IT and SE specializations introduction in standard B is enough.

4. The Bachelor direction 010500 use experience in Mathematical Faculty of Petrozavodsk State University

In PetrSU the 010500 (510200) Bachelor direction was open in 1993 [28–31] and Master of Science direction — in 1997. The curriculum was developed taking into account Computing Curricula 1991 recommendations. The faculty has graduated 269 Bachelors of Science, 191 Specialists and 73 Masters of Science for 13 years. It is significant that only few students left university obtaining Bachelor of Science degree, as a rule to continue their education in other universities including foreign institutions. The majority of the students continued their education for one or two years to obtain Specialist or Master of Science Diploma. Undergraduates frequently continued their education in postgraduate school.

Our experience verifies that B standard provides exceptional flexibility enabling to reflect current ICT changes in curriculum. For the last 13 years we have successively introduced in the curriculum “ Introduction to Processors”, “Computer Networks”, “Operating Systems”, “Software Engineering”, “Shell Language”, “Object-oriented Programming in Java and .NET environments”, “Computer Architecture”, “Web Technologies” and “SE Team Project” courses.

Due to the elective and facultative courses specialized training for “System Network Technologies” was open in 2001 where the following courses are offered: “Concurrent Systems”, “OS Unix Programming”, “Network Programming”, “Distributed Systems”.

Standard B curriculum can be easily adjusted to international requirements that our experience of curriculum common core development with Computer Science department of Helsinki University (Finland) [32] proves.

Currently the faculty is using the following sequence of ICT introductory courses (Mathematical courses are not offered).

1st term	CTC	2nd term	CTC
Introduction to ICT	0.5	Shell Language	0.5
Introduction to Processors (Assembly Language)	0.5	Introduction to Processors (Assembly Language)	0.5

Programming and Algorithms (C Language)	1	Data Structures	1
Discrete Mathematics	1	Mathematical Logic	0.75

3rd term		4th term	
Combinatorial Algorithms	1	Combinatorial Algorithms	1
Data Bases	1	Operating Systems	0.75
Computer Networks	0.75	OOP in .NET Environment	0.75
OOP in Java Environment	0.75		

This sequence concept is a parallel familiarization with a processor architecture and basic standard approaches of C procedure programming. We use our developed instruction procedure of the "Introduction to Processors" course for the first-year students with Assembler simple programs development for real processors [33, 34]. This approach particularly allows serious difficulties avoiding, that appear when object languages (Java for instance), which are analyzed in detail in [35], are used in the first course of programming.

We rest upon C and C++ languages as they are the majority of contemporary languages progenitors that are actively used in Software industry and essentially are the contemporary programming culture basis and means of communication in professional communities. It is easy to build courses on OOP methods, operating systems, network technologies, compilers' compilers and other basic ICT course on the basis of C culture.

Resume

We have examined educational standards development and deployment problem to accomplish the task of specialist training capable of long term efficient professional activity in Information and Communication Technologies sphere under its diversification and rapid considerable changes conditions. In the article it is offered to serve the growing needs for the specialists including the adjustment of existing, widely spread standards, that significantly decreases the Higher School response time to ICT sphere content and demand changes.

Reasoning from the thesis that Applied Mathematics methods are Computer Science discipline basis, we emphasize the importance of Mathematical Culture for all ICT disciplines and offer "reverse" approach to curricular guidelines development, when corresponding engineering components are introduced in the curricula, providing intensified mathematical training. As a basic curricular guideline in Russia it is natural to use 01050{0|1} standard family – "Applied Mathematics and Informatics", which is widely spread in Russian universities, has been successively approved for a long time, and its graduates have a good professional reputation.

Accomplished temporal characteristics comparative analysis of "Computer Science", "Information Systems", "Information Technologies" and "Software Engineering" disciplines Body of Knowledge Cores shows that these Cores are entirely accommodated in the study hours of Bachelor direction 010500 provided for ICT study. Standard adjustment procedure to the current ICT requirements can be conducted at the cost of four specialization introduction corresponding to CS, IS, IT and SE disciplines.

01050 {0|1} standard family adjustment approach to contemporary needs and ICT sphere state has the following advantages:
– directed integral Mathematical Culture formation;
– approved two stage schema Bachelor of Science, Master of Science;
– flexible structure providing easy reaction to ICT changes;
– easy international requirements adjustment;

– adjustment process procedure simplicity compared to development, approbation and new standards introduction processes.

01050{0|1} standard family use experience in Mathematical Faculty of Petrozavodsk State University during 13 years justifies theses offered in the article.

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