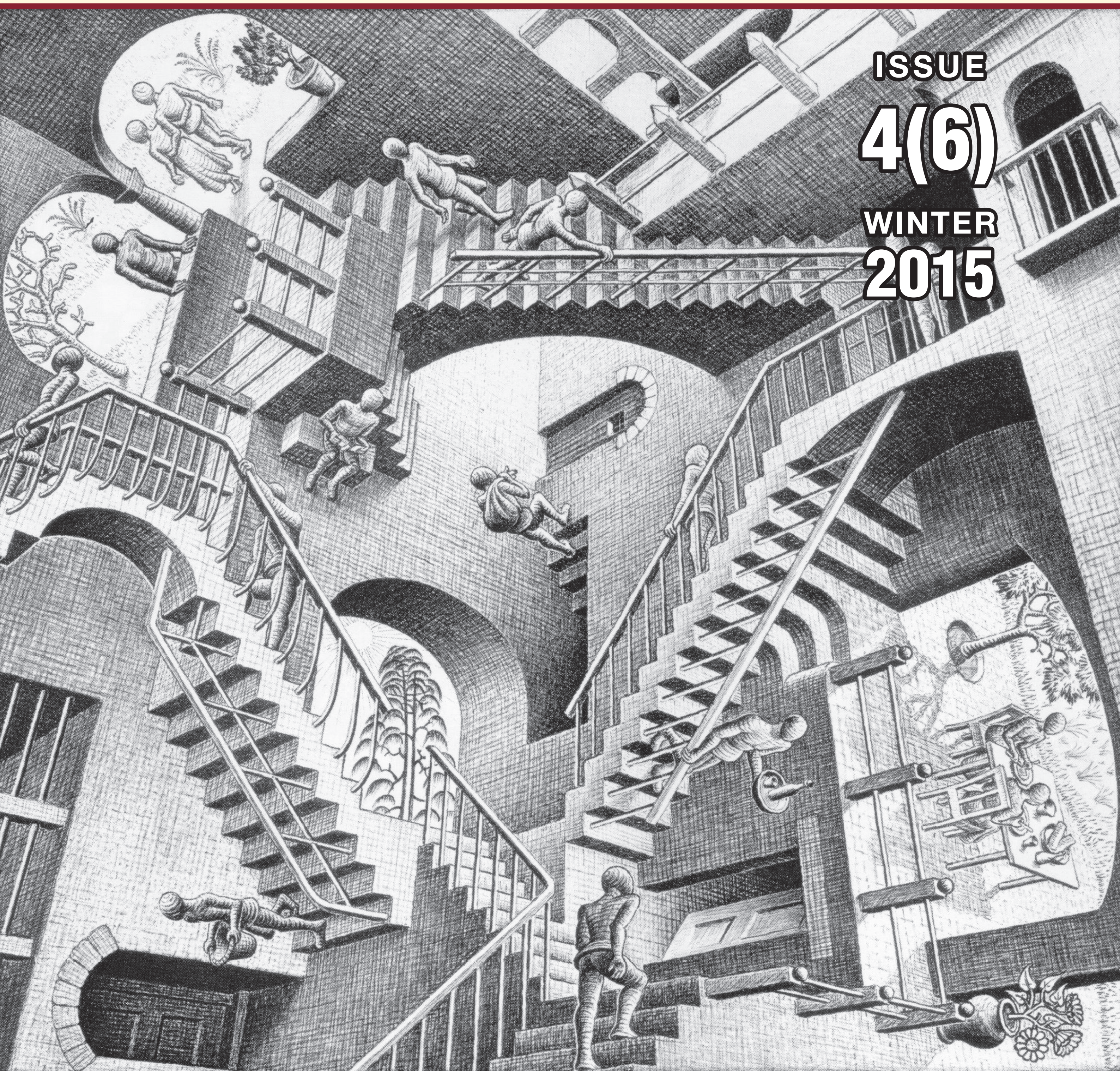
HERB

Higher Education in Russia and Beyond

From Russia with Math



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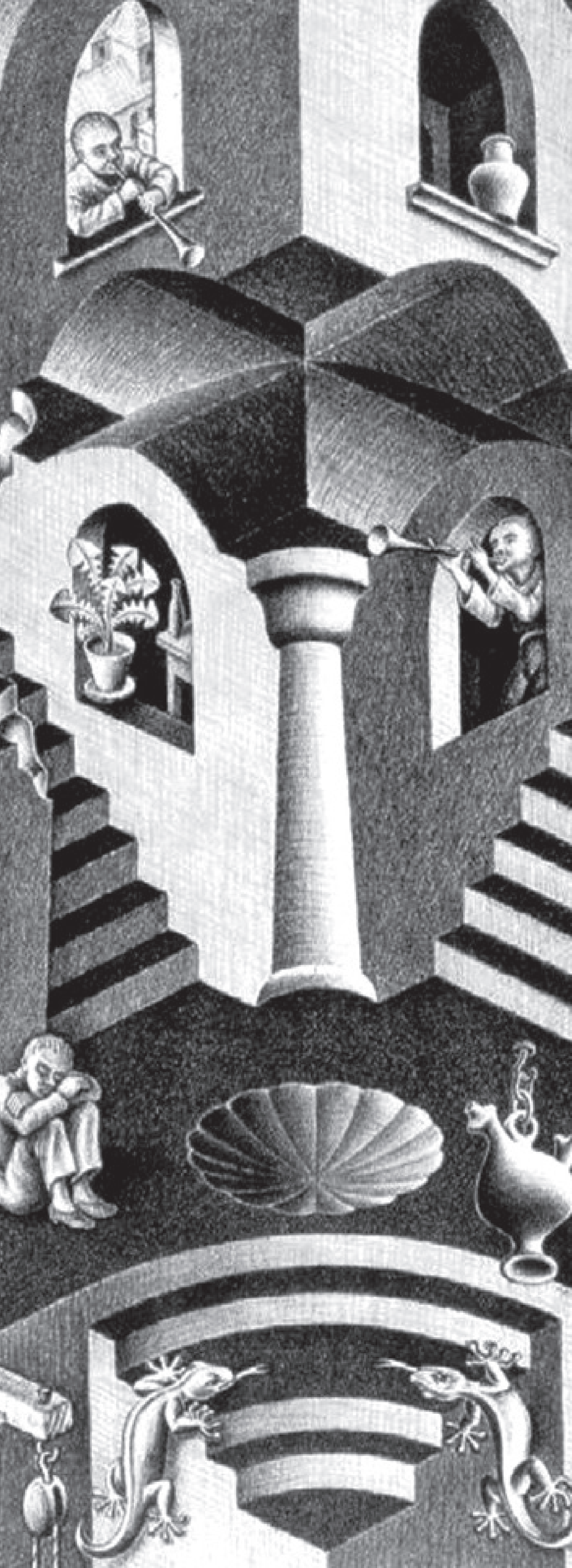

Dear colleagues,

We are happy to present the sixth issue of Higher Education in Russia and Beyond, a journal that is aimed at bringing current Russian, Central Asian and Eastern European educational trends to the attention of the international higher education research community.

The new issue unfolds the post-Soviet story of Russian mathematics — one of the most prominent academic fields. We invited the authors who could not only present the post-Soviet story of Russian math but also those who have made a contribution to its glory. The issue is structured into three parts. The first part gives a picture of mathematical education in the Soviet Union and modern Russia with reflections on the paths and reasons for its success. Two papers in the second section are devoted to the impact of mathematics in terms of scientific metrics and career prospects. They describe where Russian mathematicians find employment, both within and outside the academia. The last section presents various academic initiatives which highlight the specificity of mathematical education in contemporary Russia: international study programs, competitions, elective courses and other examples of the development of Russian mathematical school at leading universities.

'Higher Education in Russia and Beyond' editorial team

Guest editor for this issue – Vladlen Timorin,

professor and dean of the Faculty of Mathematics at National Research University Higher School of Economics.

HSE

National Research University Higher School of Economics is the largest center of socio-economic studies and one of the top-ranked higher education institutions in Eastern Europe. The University efficiently carries out fundamental and applied research projects in such fields as management, sociology, political science, philosophy, international relations, mathematics, Oriental studies, and journalism, which all come together on grounds of basic principles of modern economics.

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Mathematical Education in Universities in the Soviet Union and Modern Russia

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Traditions of mathematical education in Russia on both school and university level, research done by Russian scientists and its impact on the development of mathematics is considered by many a unique and valuable part of the world cultural heritage. In the present paper, we describe the development of mathematical education in Russian universities after 1955 — a period that proved to be most fruitful.

1. University Education in 1955-1988

In contrast to most Western countries, especially North American ones, high-level university education in the Soviet Union was concentrated in very few centers, and even among these centers, the Faculty of Mathematics and Mechanics of Moscow State University (widely known as Mechmat) was distinguished due to its unique cluster of outstanding mathematicians. The state of Mechmat mathematics determined the general situation in the country. The golden period of Soviet mathematics lasted for less than 20 years between approximately the mid-50s and the mid-70s. Both its beginning and its end were caused by political events in the country. The fall of the iron curtain and the exodus of Soviet mathematicians in the late 1980s marked the beginning of a new period.

The Golden Years of Soviet Mathematics

Outstanding Soviet mathematicians have always worked for Mechmat. However, at the end of the 1950s their concentration became incredible. In addition to the representatives of older generations, like Andrei Kolmogorov, Izrail Gelfand, Ivan Petrovskii, Igor Shafarevich, during a short period of time Mechmat hired such recent PhD students as Dmitrii Anosov, Vladimir Arnold, Felix Berezin, Alexander Kirillov, Yuri Manin, Sergei Novikov, Yakov Sinai, and several others, who determined the development of mathematics in the Soviet Union and affected the world mathematics over the next few decades. Mechmat classrooms were full of young students not only in the mornings and afternoons during obligatory classes but also in the evenings when popular research seminars were overcrowded. It wasn't only Mechmat students or professors took part in the seminars: people working for other Moscow universities and research centers or even in other Russian cities would regularly come to the seminars too. Seminar participants would either present their own research or explore the most recent results from abroad considered to be important by seminar leaders. Soviet mathematicians, as well as the rest of the Soviet people, were typically not allowed to leave the country; Western mathematicians came to Russia very rarely, and only a part of Western journals was available even in the best libraries, often after a serious time gap. Nevertheless, most of the important research results and theories reached the target audience. Practically all quickly developing domains of mathematics were well represented at Mechmat in those years.

During that period several Soviet mathematical journals that published quality papers were widely read all around the world, and many Western mathematicians decided to study Russian in order to be able to read the Russian versions of the papers before their translations appear (which could take some time). Publications in these journals were considered to be very honorable, and it was not an easy task to achieve such a publication.

Low mobility inside the Soviet Union, caused both by economic reasons and various restrictions, gave birth to many stable research schools, where dozens of people communicated regularly with one another for decades, developing rich theories. The atmosphere of mathematical enthusiasm and the obvious quality of the faculty made Mechmat attractive to strong mathematically-oriented high-school graduates, and they got probably the best possible education in the world. Of course, not all of Mechmat graduates stayed there to work, and many other universities all over the country had a chance to hire world-level faculty of a very high quality. Leningrad State University, which is the oldest Russian university, had several high-quality research schools of its own. Mathematicians were among the founders of Novosibirsk State University in 1959, which shortly after that became a leader in several research areas, while there were one or two research schools in a specific domain in many other universities. Flexibility and high quality of education in these leading universities allowed their graduates to play crucial roles in the years to follow in the development of computer science and information technology in the Soviet Union.

At the beginning of the 1960s, 4 leading universities established boarding schools for talented high-school students. University professors, as well as specially selected teachers, gave lectures in these schools. Best pupils from all over the country, especially from small towns and villages, were agglomerated in these schools in order to prepare them for future research careers. In a few years, this network of boarding schools extended and was supplied by specialized schools in big cities. Kvant monthly magazine, which started in 1970 and explained deep notions in mathematics and physics to high-school students, reached 300 thousand subscribers [1]. Each year the Correspondence school (school of distanced education) founded and ruled by Gelfand taught hundreds of high school students all over the country. As a result, in subsequent years universities got a lot of well-prepared freshmen.

The Period of 1970–1988

Since late Stalin period (early 1950s), people of Jewish background were considered by authorities as suspicious (although this was not officially admitted). For many years, this was not a serious problem in physics and mathematics, since leading physicists managed to explain to the government that developing new kinds of weapons and space program required attracting all capable people, no matter what their ethnicity was.

The situation had changed by the end of the 1960s after several public political manifests by leading scientists. Mechmat top administration was replaced, and the local Communist Party group started to play an important role in the student admission process (to both undergraduate and graduate programs), as well as in the faculty hiring process. Similar problems arose in other top universities. As a result, strong students who were suspected of having Jewish roots were no longer accepted to leading universities. In some cases, even line-up of the Soviet team for the International Academic Olympics was affected by the same tendency [2]. Local efforts to improve the situation (for example, for several years such students could study at the Department of Applied Mathematics of Moscow Institute of Gas and Oil) could not lead to principal solutions.

Taking into account that many leading physicists and mathematicians were of Jewish origin (it suffices to recall that five out of eleven Russian Nobel prize winners in physics have Jewish roots), and a traditional Jewish affection for natural science studies, one may conclude that Soviet universities and, later, Soviet science lost a good deal of talented people.

The period between 1970–1988 can be considered a period of stagnation, without serious exceptions. Higher education faculty, especially in leading universities, did not improve since political loyalty was valued much higher in the process of hiring people than professional qualities. When Soviet citizens of Jewish origin were finally granted a restricted right to emigrate to Israel, it became even more difficult for them to enter a university or find a decent job. Many of those affected by the situation chose to leave the country.

Mathematical Societies in Russian Cities

Nowadays mathematical societies play an important role in organizing the social life of mathematical communities all over the world. It suffices to mention the American Mathematical Society, the London Mathematical society, the European Mathematical society, and so on. They advertize vacancies, publish books and journals, discuss school and university curricula, organize regular meetings. There is no national-level association of comparable status in Russia. The Soviet Mathematical Association, established in 1934, did not succeed in becoming a serious organization that would unite the community, and was dissolved by 1960.

In contrast, mathematical societies of certain cities were active and, for certain periods, flourishing. The oldest one, the Moscow Mathematical Society, was established in 1867 and has been active without serious interruptions till now. In 1960-1990, it was headed by Aleksandrov, Kolmogorov, Gelfand, Shafarevich, Novikov. Its regular weekly meetings at Mechmat were attended by dozens of Moscow mathematicians. The Society published several respectable journals. Other pre-revolutionary societies like Kharkov and Leningrad ones were active too, as well as newly established societies in other cities. Being non-governmental organizations, these societies defined the community's moral and academic standards.

2. Current State of Mathematical Education at University Level

Several processes that began around 1988 have seriously affected mathematical education in Russia. Among them:

- disintegration of the Soviet Union;
- fall of the iron curtain, which gave Soviet mathematicians an opportunity to leave freely for the West;
- quick growth of both the number of universities and student enrolment in Russia;
- introduction of the obligatory state exam for high-school graduates;
- splitting of university education into two stages: 4-year bachelor programs and 2-year master's program, instead of the traditional 5-year "specialist" education.

Some aspects of mathematical education have survived these processes but the very necessity to survive weakened them a lot. Thus, the Kvant journal, as well as Correspondence School, still exist but they do not affect mathematical education anymore due to the small number of participants. Nevertheless, this does not mean that mathematical education in Russia is in crisis, as Russian knowledge of how to teach and do mathematics is still highly demanded in the world.

Impact of the Post-1988 Period on Mathematical Education

Simultaneously with the disintegration of the Soviet Union, Russian economy collapsed. The country's financial system was in a poor state, and for about ten years in a row universities got very small financial support from the government compared to the preceding years. At the same time, state control over education and its outcomes weakened dramatically.

An increase in the number of universities led to more corruption in the university admissions process (which in those times relied on the system of entrance exams).

In many cases, corruption part of the educational process at later stages too: students were expected to pay for passing exams. Although mathematical departments were affected by this problem less than, for example, those of medicine, economics, or Law, they experienced certain negative effects as well. The introduction of the Unified State Examination in 2002 was aimed at improving education at high-school level and tackling corruption at university entrance exams. Unified State Examination in mathematics is obligatory for all high-school graduates. It has been highly criticized by many experts because of a standardized approach to problems, which cover only a part of high-school mathematics. Criticism became less concentrated after 2010 when multiple-choice questions were excluded from the exam but corruption accusations against the system of Unified State Examinations on the whole remained high till 2014.

Most of good, specialized high schools all over the country survived the complicated period of 1988–2000 without serious loss of quality. In contrast, the average level of education decreased dramatically. Despite the lack of comparable data, practically all experts agree that most university freshmen's mathematical background is much lower now than in the 1980s.

University Education Centers

Emigration of many leading Russian mathematicians, which reached its heights after 1988, dramatically weakened both higher education and research in Russia. For example, all the Fields medalists of Russian origin have permanent positions in the West (the only exception, till recently, being Grigori Perelman, who does not work for Russian institutions anymore anyway). Thus, it is estimated [3] that more than 300 active Russian mathematicians found permanent positions in American universities after the disintegration of the Soviet Union, while more than 1000 in total left Russia and moved to the USA. The former's combined scientific productivity was greater than that of their American colleagues: during the period 1992–2008, each of them published on average 20 papers more, and got 143 references more.

Nowadays Russian public universities have about 130 departments teaching math majors [4]. Leading scientists teach at only few of them. As a result, the average level of research in most of the universities is lower than that in the US, Canadian or Western European universities. Teaching level is low too: professors who don't do research teach badly prepared students.

Academic inbreeding is wide-spread. There is no real competition in the process of hiring. With few exceptions, regional universities admit only high-school graduates from the same region. Regional universities do not compete for mathematics students, and they are not attractive for young people interested in math.

While there were more than 30 out of the 80 invited speakers at the International Congress of Mathematicians in Berkeley (USA) in 1986 came from the Soviet Union (most of them from Russia), only 5 Russians (among 170 speakers) were invited to give talks at the Congress in Hayderabad (India) in 2010. When compared to European and North-American countries, Russia hosts much fewer conferences, and with fewer foreign participants.

Nevertheless, new centers of mathematical education have been established in Russia in the recent years, and they have already gained world-wide recognition, namely:

The Independent University of Moscow (founded in 1991)

- and (closely related to it) Faculty of Mathematics at National Research University Higher School of Economics (founded in 2008).

In September 2015, a new bachelor program was launched at St. Petersburg State University.

The Principles of Developing Mathematical Education in Russia

The government realizes the importance of mathematical education for national economic development and the need to improve it. On December 24, 2013, the government approved The Principles of Developing Mathematical Education in Russia. However, its practical implementation is planned to start in 2016, and for now, the results are difficult to predict.

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[1] For example, the running data of Kvant issue no.10, 1974 at the website **http://kvant.ras.ru/oblozhka_djvu.htm** *indicates the number of published copies as 361,090*

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The Principles of Developing Mathematical Education in Russia, approved by governmental decree N 2506-p of 24 December 2013.

Reasons for the Success of the Soviet Mathematical School

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It is widely known that Soviet school of exact sciences, was among the strongest in the world, particularly in terms of physics and mathematics. Why? This is the question we would like to address in this paper by collecting and summarizing different viewpoints on this issue expressed by prominent mathematicians. Many of them witnessed the most fruitful period, the "golden years" of Soviet science and played a major role in the subsequent development of Soviet/Russian mathematics. There is little controversy in the explanations provided by different people; the only essential differences are in the emphases. Thus the list of factors may be regarded as precisely determined. This paper simply aims at communicating them to a non-mathematical community interested in issues of science and education.

The 1950s–1960s are considered to be the golden years of Soviet mathematics. To be more precise, according to V. Tikhomirov [Ti], this was the second peak, the first one being the pre-war period of the 1920s–1930s.[1] Here, however, we will mostly write about the second period. It is important to note the following historical events that are relevant for defining the period: the death of Stalin in 1953 and the "Letter of 99 Mathematicians" in 1968.[2]

V. Vassiliev [Va] lists the following three major reasons for the success of Soviet mathematics:

- Significant support from the government and high prestige of science as a profession. Both factors are related to the rapid industrialization efforts of the USSR.
- Doing research in mathematics or physics was one of the very few intellectual activities that had no mandatory ideological content. Many would-be historians, philosophers or economists (even artists, musicians or computer scientists) became mathematicians or physicists.
- The Iron Curtain preventing international mobility. (Vassiliev adds that the relatively high share of Jews, who would traditionally opt for intellectual professions, proved to be advantageous too, cf. [Fu])

These are specific factors that shaped the structure of Soviet science. Certainly, factors 2 and 3 are more on the negative side and cannot really be called favorable but they essentially came together in combination with the totalitarian regime. Nowadays, it would be impossible to find a scientist who would want the three factors to be reproduced in their totality.

Basically, all the more specific explanations elaborate on one of the three factors just listed. Speaking of the state support, one may mention a very strong inclination towards physics and engineering across all educational levels. This manifested at school-level: mathematical curriculum in Soviet high school was by far more advanced than in most other countries, including modern Russia. Pierre Deligne [De] also mentions the Mathematical Olympiads tradition. The tradition of mathematical circles is obviously relevant too. At university level, there was significant demand for instructors of math and physics for engineers. Why were so many mathematicians, physicists and engineers needed? Experts refer to rapid industrialization, the space exploration program, the nuclear program and, more generally, to the fast growing military industry, cf. [Sm].

Elaborating on the ideology factor, M. Tsfasman [Ts] describes the period of about 20 years after 1953 as a unique combination of freedom and totalitarianism. Although it is hard to talk about freedom in its usual sense when referring to the 1950s–1960s, a number of barriers of the late Stalin period were removed, and the smell of freedom was distinctively recognizable in the air. As M. Tsfasman narrates in [Ts], "My teacher Yuri Ivanovich Manin once told me that the most significant visual impression of his youth was when in 1953 they demolished all the perimeter fences or, more precisely, only about half of the fences were left." Many career opportunities opened up around that time. However, only very few careers did not require their adepts to publicly express, in speech and writing, the loyalty to Soviet regime and communist ideology. A. Sossinsky [So] comments: "If you play the violin — it's great! But if you want to be a composer — too bad, since they will look not only at what you compose but also at how you do it". An advantage of being a mathematician (or a physicist) was that you did not have to lie.

Together with the impossibility of international mobility (very few exceptions notwithstanding), experts say that mobility within the country was heavily obstructed too by the fact that there were only very few centers (most of them situated in the biggest cities), where fundamental research was possible as a primary occupation. On the other hand, living conditions outside the biggest cities were poor. This, as V. Tikhomirov [Ti] confirms, created an unprecedented concentration of bright scientists in few places and led eventually to the development of a unique school. Commenting on scientific schools and their relative strength, M. Tsafsman [Ts] gives the example of the French mathematical school, which consistently produced first-rate results over a long period of time and where an extensive collaboration took place, and the British mathematical community, which gave rise to many prominent scientists but failed to form a "school" due to lack of collaboration. A school is not only a large group of closely collaborating individuals but also a group tied densely with student-advisor relationships. This is why the USA, currently the world's leader in terms of the level and volume of mathematical research, does not have scientific schools in this sense: the level of mobility there is extremely high. One can talk not only about the Soviet school of mathematics but also, more specifically, of the Moscow, Leningrad, Kiev, Novosibirsk, Kharkov and other schools. In all these places, there were constellations of distinguished scientists with large numbers of students, conducting regular seminars. These were not merely advisors but also spiritual leaders.

Since 1970s, all the three factors have been gradually fading, and the level of mathematical research in Russia has been gradually declining too. According to [La], the situation has recently stabilzed but at a very low level.

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[1] The two periods are of course not independent. The development of science in between the two periods was obstructed by Stalin's repressions of the late 1930s and the Second World War. In the 1920s–1930s, Leningrad school of mathematics was a continuation of the pre-revolution tradition, whereas mathematicians in Moscow developed under strong influence of the French school.

[2] A letter signed by 99 Moscow mathematicians, addressed to Soviet authorities asking for the release of A. Esenin-Volpin, a prominent mathematician, poet and dissident, who was confined in an asylum against his will and without prior medical examination; see, e.g. [Fu]. Full text of the letter is available at **http://www.math.ru/history/p99/index.htm** *(in Russian).*

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A Metric View on Russian Mathematics and Russian Mathematical Diaspora

(A Study Based on Frequent Russian Surnames)

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What happens with Russian mathematics in terms of metric parameters? Where do Russian mathematicians work, where do they publish, how well are they cited?

"Russian" may refer to different things: to one's current workplace or to one's origin. First, let us consider "Russian" in terms of origin. We conducted a numerical experiment, which serves to approximate the dynamics of mathematical research produced by scientists originally from Russia. It is difficult to identify this group of mathematicians in citation databases. Instead, we picked some most popular Russian surnames and checked the publication output of people with these names in the Web of Science database. We hope that the chosen collection of scientists is somewhat representative because the authors with these surnames coauthored almost a third of Russia's articles and reviews across all disciplines in the Web of Science in 2014. We call our collection "frequent Russian surnames," or FRS. As of 1994, about 70% of all FRS-coauthored publications were affiliated with Russian institutions. This indicates indirectly that FRS may provide a fair representation of Russian mathematical community. In particular, we expect that FRS migration correlates with the migration of Russian mathematicians, etc. One drawback of the chosen scheme is that it does not distinguish between Russian and, say, Belorussian scientists (the latter form about 3% of the FRS). It is worth noting that those FRS which are also popular in Bulgaria (Ivanov, Antonov, Markov, etc.) were omitted.

Migration of FRS Mathematicians

We see at Figure 1 that in the 1990s, a significant part of FRS scientists were terminating their Russian affiliations and accepting affiliations outside of Russia. This process stabilized in 1998. The percentage of FRS scientists combining their Russian affiliations with affiliations abroad has been steadily growing.

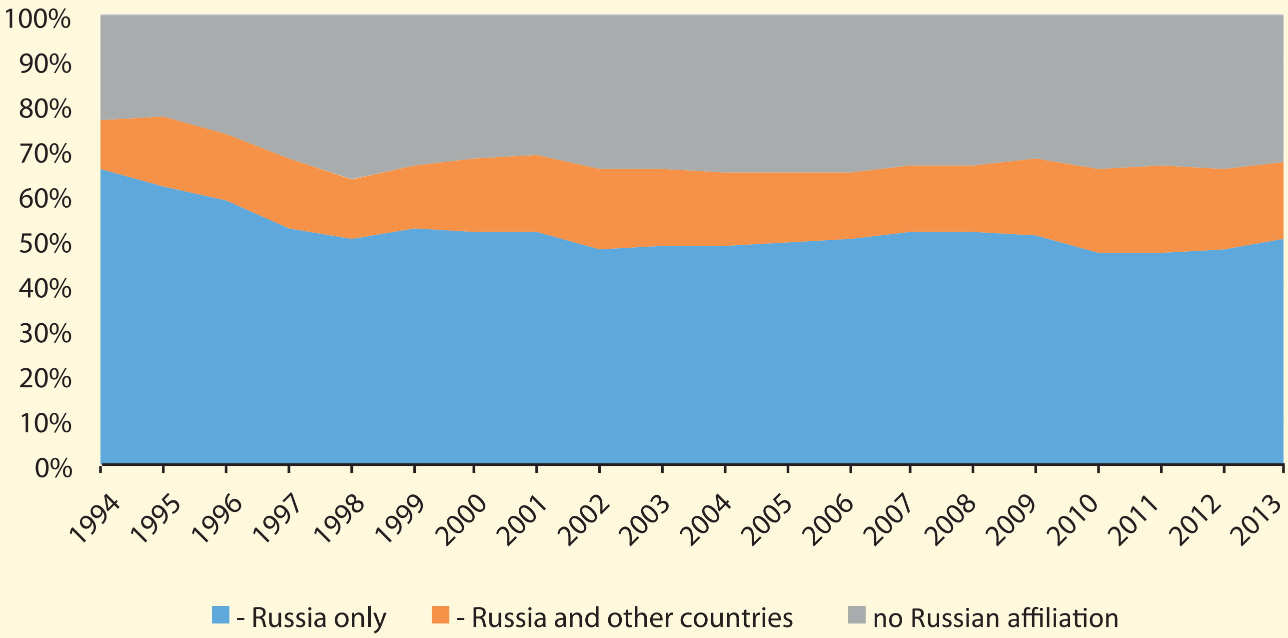

Figure 1. Share of FRS publications by type of affiliation

Figure 2 left shows the most common country affiliations of the part of FRS not affiliated with Russian institutions. Note that a significant part of FRS resides in Belarus and Ukraine, which is natural because many Belorussian and Ukrainian surnames are the same as Russian ones. It is safe to assume that FRS scientists affiliated with Belorussian and Ukrainian institutions did not move there from Russia (with some statistically negligible exceptions).

The most popular emigration destinations were the USA, the UK, Germany, France and Canada, see Figure 2 right. This is not surprising. Note also that the USA alone hosted more than a third of all FRS emigrants

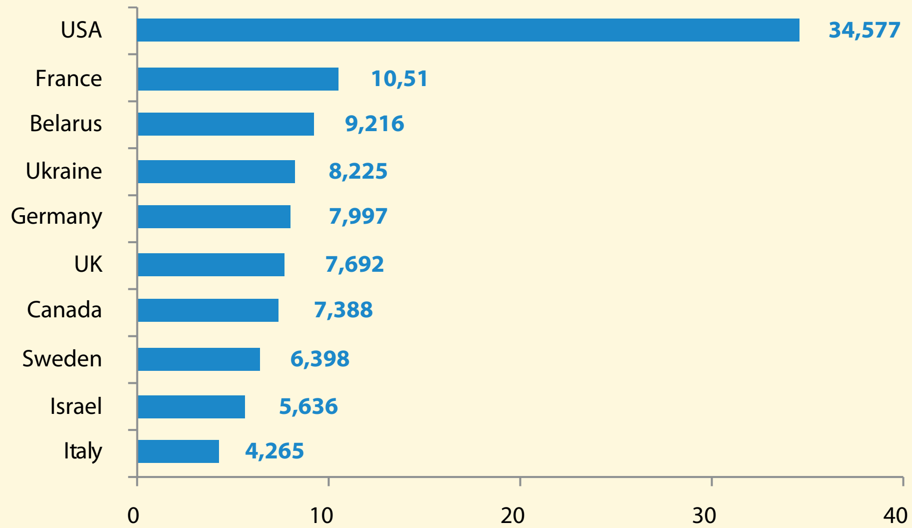

Figure 2. Share of FRS-authored papers by country, 1993-2015

1993-1995			2012-2014		
Countries/Territories	**records**	**% of 42**	**Countries/Territories**	**records**	**% of 185**
USA	19	45.238	USA	83	44.865
FRANCE	7	16.667	UK	28	15.135
ISRAEL	5	11.905	GERMANY	23	12.432
GERMANY	4	9.524	FRANCE	20	10.811
SWEDEN	3	7.143	CANADA	16	8.649
CANADA	3	7.143	IRELAND	14	7.568
			ISRAEL	13	7.027
			SWEDEN	10	5.405

Scientific Output from Within and Outside of Russia

It is interesting to compare scientific output of FRS scientists with and without Russian affiliations. First of all, we looked at the journals where they published. It looks like Russia-based scientists prefer domestic journals, whereas the overseas part of FRS try to publish in high-impact international periodicals. We counted FRS publications in the top 25 pure mathematics journals (based on the MCQ [1]; it may be instructive to observe that the distinction between pure mathematics journals and applied mathematics journals is not obvious, and our specific choice may be questionable). Out of 1027 FRS publications without Russian affiliations, 203 are on the "top-25 journals" list. On the other hand, out of 2747 Russian publications, only 83 are. Russia-based and overseas FRS publications are drastically different in terms of citation numbers. For example, for Russian publications, the average number of citations per item is 2.66, whereas for overseas publications — 7.48. By the way, the average number of publications per author is also lower among the "domestic" part of FRS, although the difference is not that significant.

We can conclude that the overseas part of FRS are more efficient in their research, at least in terms of metric values. We can list several specific reasons for that. It is hard to estimate relative importance of these reasons, though:

- Russian emigrants appearing in our data sheets are those who were able to find good academic positions abroad. This by itself distinguishes them as being scientifically productive or at least respectable at the international level. It is also interesting to note that Russian emigrants appear to be more productive than domestic scientists in their host countries, see e.g. [2].
- There are Russian universities with many publications in mathematics and few internationally recognized mathematicians. Employees of these universities publish a certain amount of papers simply to comply with "publication activity" requirements imposed by their institutions. Note, however, that we are only looking at publications indexed by the Web of Science (WoS), i.e., at publications in reputable journals.
- In Russia, average salaries in mathematics are low. Thus, mathematicians have to combine research with other activities in order to earn a decent living.

Mathematics in Russia: Publications in the Top 25 Journals

Now let's leave the FRS list aside; instead, we will talk about all scientists with Russian affiliations. Figure 3 shows the level of publication activity by country in the top 25 mathematics journals (measured as percentage of the total number of publications in these journals in the WoS; a publication contributes equally to all countries listed in the affiliations of the authors). The Figure shows the top 8 counties except for the USA, whose graph is higher than the upper boundary of the figure; it exhibits a regress from 52.4% to 45%.

Russian mathematical journals were not among the top 25 journals we considered. All the 25 journals are published in the West. When looking at Figure 3, one should keep in mind that it is traditional in Russia to publish in the best Russian journals (like Russian Mathematical Surveys, Mathematical Notes, etc.), which are very competitive at the international level but whose citation-based numerical measures are lowered by several circumstances including the fact that the citations are split between the Russian original and the English translation. Having this in mind, Russian mathematical output stands surprisingly high despite the exodus of a better part of mathematicians. On a negative note, no significant progress is visible (cf. China!).

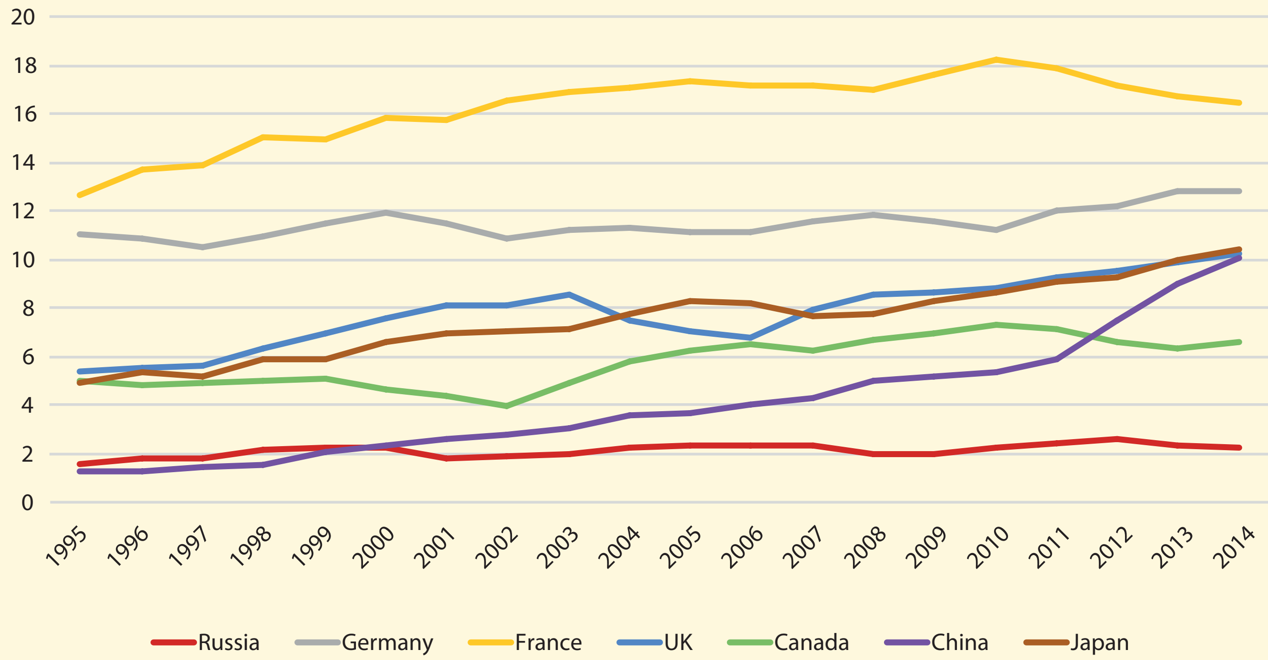

Figure 3. Share of publications in top 25 general interest mathematics journals by country

The Academy of Sciences vs. Top Russian Universities

An important feature of science in Russia is that the Russian Academy of Sciences (RAS) is comparable in its academic output with the totality of all universities. This can be seen from Figure 4 left, where publication activity of the RAS vs. the top 17 universities is shown. [3] It is also clear that Russian scientists have been moving from the academic institutes of the RAS to universities, or at least accepting part-time positions in universities together with their full-time positions within RAS.

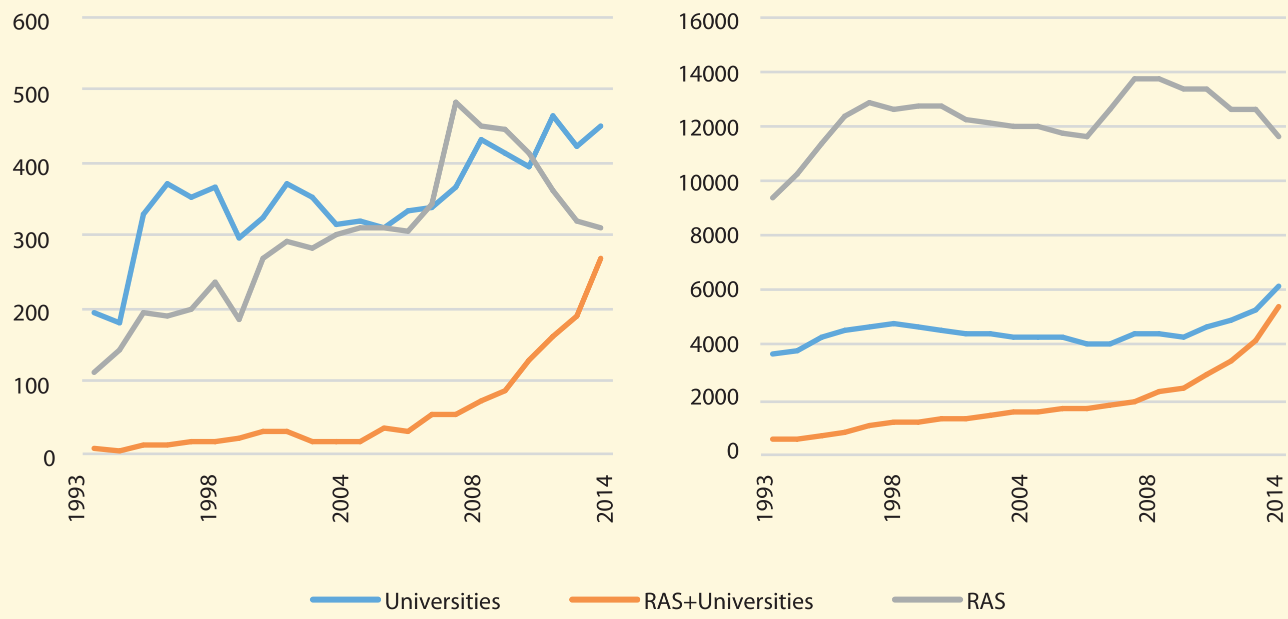

Figure 4. WoS publication counts. RAS vs top 17 Russian universities. Math (left), all disciplines (right).

It is interesting how prominent this process is in mathematics, see Figure 4 right: universities produce a bigger share of publications, they are hiring new faculty or stimulating publication activity of existing faculty more aggressively.

To sum up, we see the following picture based on our numerical study: Russian mathematics has lost its best representatives; nevertheless, it still stands very high at the international level. The decline has come to an end but no significant progress is currently visible. We should stress, though, that metric values give only a very rough picture, oftentimes distorted by various database peculiarities not directly related to the discipline itself. A comparison of particular universities or even particular countries should not be based on such values exclusively.

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[1] The MCQ is calculated by counting the total number of citations into the journal that have been indexed by Mathematical Reviews over a five-year period, and dividing this total by the total number of papers published by the journal during that five-year period.

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[3] 15 universities initially selected by the RF government for the 5-100 project plus Moscow State University and Saint-Petersburg State University

5-100: Russian academic excellence project, http://5top100.ru/

Math Graduates' Career Prospects in Modern Russia

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"A mathematician will do it better"
Hugo Steinhaus

What can mathematicians do in applied science or other disciplines? First of all, mathematicians teach students of other fields math. Second, they prove theorems. Sooner or later, unexpectedly many of these theorems find some kind of application.

Yet, there is also another obvious answer, which is probably even more important in terms of technological development; it also helps create much more jobs for people with a degree in math. I'm talking about the fact that science and technology in general are becoming more and more mathematized.

We will briefly talk about the mathematization of science in the Soviet and post-Soviet periods and discuss the job prospects mathematicians have in modern Russia.

1. Historical Background

The mathematization of knowledge is one of the major processes going on in culture and science. The level of mathematization of a given discipline is a sign of its academic maturity and applicability.

However, this is a fundamental truth that was forgotten for nearly 1500 years after the end of the Antiquity, when pythagoreanism flourished. In the Middle Ages and during the Renaissance, mathematics was solely viewed as a skill, only required by merchants or engineers. It was taught at professional schools (e.g., "abacus schools" in Italy) but not at universities. Mathematics continued to develop and to slowly penetrate other spheres of knowledge only with the help of some random autodidacts, be it university professors or military engineers.

In the Early Modern Period, the situation changed dramatically. It turned out that math was necessary in order to process the empirical achievements of the Renaissance. One can quote Carl Friedrich Gauss, who said, paraphrasing Newton, "Mathematicians stand on each other's shoulders." When new means of communication became widely accessible to scientists all across Europe, they finally managed to "stand on each other's shoulders" in math. The traditionally low level of mathematical literacy common among professionals was no longer sufficient as it didn't measure up to the challenges of capitalism, gunpowder, and the Age of Discovery.

By the beginning of the XVII century, a new attitude had developed: universities needed pure mathematics, and mathematics graduates could find professional employment in applied spheres. The Age of Reason was starting. Universities were, one after another, opening new chairs of mathematics, the first among them being the Lucasian Chair of Mathematics and the Savilian Chair of Geometry. Some countries joined the process too late, and their universities would later regret their conservatism as they had to give way to schools of applied sciences (e.g., engineering schools in France), which had "sheltered" pure physicists and mathematicians.

Since those times, higher education institutions offer degree programs in mathematics. Some graduates of these programs become pure mathematicians, while others pursue different careers expanding the influence of mathematics on external fields of knowledge that are mature enough for such a connection. The list of such fields is growing constantly and might look surprising now. For example, two centuries ago economics was clearly considered to be part of humanities, and it was hard to find a research article that would contain a complicated equation. Nowadays, however, nearly half of all Nobel Prize winners in economics have a BA in math or physics.

It is not just the mathematization of knowledge that pushes demand for math graduates on the labor market; there are other reasons too. To put the popular theory of job-market signalling (developed by an economics Nobel Prize winner with a background in math) simple, an employer sees a potential employee's diploma as a sign of the latter's motivation, ambition and skill rather than a document that certifies the fact that a job candidate has obtained some specific knowledge. From such a perspective, having a degree in math is a huge advantage on the labor market: "The value of mathematics is the fact that it's hard" (A.D. Aleksandrov). This is why employers often hire mathematicians to do creative, abstract work even if it has nothing to do with math per se.

2. The Role of Math Graduates in the USSR and in Russia

The first thing many readers would think of once they've seen the subtitle is nuclear weapons. Yet, we believe that Soviet mathematicians' contribution to arms industry wasn't unique and shouldn't even be considered as their main service to the country.

The rate of mathematization in physics and other sciences increased drastically in the 1920s. For the following three decades, the USSR was an extremely isolated country. Academics were prohibited from maintaining contacts with their foreign colleagues, and such cutting-edge disciplines as cybernetics and genetics, where math could be applied, were simply banned. It took the Soviet Union another 30 years before it allowed certain branches of economics, actuarial mathematics, quantitative finance, biostatistics and other disciplines that were simply irrelevant for the Soviet economic and political system into the country.

As a result, it was the same sad story in many fields: Russia was lagging behind Western countries, which had had time enough to develop these areas in a way that they were already very abstract or math-rich. It turned out, however, that it's easier for mathematicians with zero knowledge of the subject to overcome such a methodological gap than it actually is for specialists in the field who have no mathematical background.

The history of economics in post-1991 Russia provides a perfect example. Many of the economists and financial experts trained in the Soviet union were inadequately prepared for the new economic system. Leonid Kantorovich, a Soviet Noble Prize winner and a prominent theoretical mathematician, was one of the pioneers who applied mathematical methods in economics. Yet, by 1991 there were few specialists in the USSR who could teach and develop modern economics according to international standards. At the time, most of them were fellows at the Central Economic Mathematical Institute of the Russian Academy of Sciences, and most of them had a background in mathematics; some of them are world-famous mathematicians (e.g., Fyodor Zak, Dmitry Piontkovsky).

CEMI director Valery Makarov (who also happens to be one of L. Kantorovich's most prominent disciples) succeeded in using his employees' knowledge and international networks in order to create the New Economic School — the country's first world-class master's program in economics. In the first years of the program, most of the students were graduates with diplomas in exact science; they would later become the first Russians to pursue post-graduate degrees in economics at the world's best PhD programs. Many of them came back and took leading positions both in Russian higher education (in particular, in the New Economic School and Higher School of Economics) and in Russian economy & finance.

The branches of economics and finance that were not covered by the New Economic School were largely revived by people with a background in exact sciences too. Before the Revolution of 1917, for example, Russia used to be one of the world's leaders in actuarial science; the World Actuarial Congress was scheduled to take place in St. Petersburg in 1915 (but never did due to the outbreak of World War I). After the revolution, this discipline was rendered irrelevant, so most of its aspects (except life insurance, for example) had to be "reinvented" in 1991. This was a long process that culminated in 2008 when the Russian Guild of Actuaries became accredited as a full member of the International Actuarial Association. Most of the 150 best Russian actuaries, who have achieved Fully Qualified Actuary status, graduated in physics or math rather than economics or finance.

The situation in programming and computer science in the Soviet Union was relatively better: in 1948, the ban on everything that had to do with cybernetics was finally lifted for the purposes of developing the arms industry. Physicists and mathematicians were actively involved in creating new institutes and university departments dedicated to computer science. One can name Yuri Neimark, who created the first ever Department of Computational Mathematics and Cybernetics in the country (in Gorky State University, nowadays known as Nizhny Novgorod State University), and Mark Ayzerman, the pioneer of intellectual data analysis at the Institute of Control Sciences of the Russian Academy of Sciences. Both of them were among the disciples of physicist Alexander Andronov. The Institute of Control Sciences gave the world such people as Vladimir Vapnik, Alexey Chervonenkis, and Ilya Muchnik. In 2007, the latter became research supervisor of the

School of Data Analysis. Its role in the development of computer science and programming in Russia is similar to that of the role of the New Economic School played in terms of economics and finance.

Credit for the fact that the country is no more lagging behind the West in many sciences, like it did in the times of the Iron Curtain, should be given to Russian physicists and mathematicians.

3. Prospects

Nowadays there are at least three other areas where demand for mathematicians is high.

First of all, Russia needs to develop new innovational disciplines that emerged earlier in the West. As mentioned before, it has managed to overcome the gap in the sphere of economics and computer science but there's a whole range of areas (e.g., in natural sciences and engineering) where the process hasn't even started yet due to lack of resource base. In some fields it is already being accumulated but it is also necessary to form an initial pool of specialists who would first get an appropriate education themselves and then start training future generations. Experience shows that in the end, such stories help create new labor market opportunities for physicists and mathematicians.

Secondly, new disciplines are emerging all the time. Their scope and professional & educational requirements often are still vague even in the most progressive countries. Such areas include mathematical methods for drug design or quantum computers and communications. This is where new international labor markets for physicists and mathematicians are developing too. If Russia timely invests sufficient funds in the development of such areas, it will likely become one of the world's innovations leaders.

Thirdly, Russia is finally able to offer internationally competitive employment opportunities to academic mathematicians. Holders of foreign PhD-diplomas in math are now coming back to Russia to take up new jobs. The introduction of postdoc-equivalent positions at some of the Russian universities and research centers gives talented young mathematicians a chance to build a successful academic career within the country.

Math in Moscow: Conveying Traditions of Russian Mathematical School

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Math in Moscow (MiM) is the name of a short-term (1-2 semesters) study abroad program offered in English jointly by the Independent University of Moscow (IUM), National Research University Higher School of Economics (HSE), and Moscow Center for Continuous Mathematical Education (MCCME). It was first launched in spring 2001 by IUM. Along with courses in mathematics and computer science, students can study Russian language, Russian literature, history of mathematics and science, and history of Russia. All MiM courses are credited to the students at their home institutions.

The main goals of the program are to:

- intensify the interaction between Western and Russian (not only mathematical) cultures;
- make Russian traditions of teaching mathematics available to international students;
- provide an international learning environment to IUM students;
- provide an international teaching experience to IUM instructors;
- broaden foreign students' understanding of contemporary Russia.

The biggest difficulty encountered by MiM in pursuing these goals is not program-specific; it rather applies to all internationalization efforts in Russia. Potential students have certain stereotypes about life in Moscow and Russian people that are hard to break. Thus, MiM's efforts to overcome these stereotypes may have cultural significance, not bounded to mathematics only.

The MiM program aims at combining the best traditions of Russian and Western systems in teaching mathematics. We have adopted the North American custom of giving significant homework assignments. Grading follows Western traditions and takes into account the results of students' activity during the whole semester. Teaching methods follow Russian traditions: rigorous theory presentation with full proofs, solving meaningful rather than formal problems, involving students in collective problem discussions. Questions are welcome in class, if not required.

Teaching international students in the MiM program, as well as teaching Russian students at IUM, is very individual. The list of courses for each semester is formed in accordance with individual application forms. Each student has an opportunity to learn as much mathematics as he/she chooses. We've had students who took up to 7-8 courses per semester.

The program provides gifted foreign students with a rare opportunity to study in a big group of talented classmates. The students, chosen from leading US and Canadian universities, form an extremely strong math-oriented group they would've never seen at undergraduate level in their home universities. This stimulates their abilities and makes teaching more efficient.

In 2008, when Higher School of Economics created the Faculty of Mathematics together with the Independent University of Moscow, MiM became a joint effort between IUM, HSE and MCCME. This gave international students even more opportunities to contact Russian students. They live in the dorms together with HSE students and may take courses offered by the Faculty of Mathematics in English. Participants of the HSE Master of Science program in Mathematics (both foreign and Russian) may take MiM courses too.

Since prerequisites for the program are rather low, we've had students of very different level. About 35% of the participants were juniors at their home universities, 35% — seniors, 15% of — sophomores, 15% had just graduated. This difference in level stimulates team work. Living in one dormitory, students often discuss math problems and lectures. Groups are extremely small in size, which allows individual approach to each student, no matter what their level is.

Besides teaching mathematics, the program offers excursions and trips, in particular, a three-day trip to St. Petersburg and a two-day trip to ancient Russian towns Vladimir and Suzdal.

Since spring 2001, more than 300 students from over 160 universities have participated in MiM. We have had, among others, participants from the following institutions: California Institute of Technology, Cornell University, Harvard University, Massachusetts Institute of Technology, McGill University, University of California at Berkeley, University of Chicago, University of British Columbia, University of Montreal, Yale University. Though the program is mostly oriented on American and Canadian students, we've had six students from Europe too.

MiM started in 2001 as a pilot program between Cornell University and IUM. The first and unique student in the first semester of the program was Alex Smith from Cornell. Soon after that, the American Mathematical Society, led by its President Felix Broder, started to award NSF-sponsored fellowships to selected American students going to MiM. A few years later, the Canadian Mathematical Society, led by its President Christiane Rousseau, started to award similar fellowships sponsored by the CMS and NSERC to Canadian students.

In 2010 and 2013 we asked our alumni about the role of Math in Moscow in their education and its impact on their careers. It turned out that almost all our alumni had chosen to continue their studies at graduate or postgraduate level. Several alumni have already got their PhDs and work at mathematics departments of different universities.

Many alumni tell that:

- MiM has had a strong impact on their decision to pursue a degree in mathematics;
- their stay at MiM determined their current field of research;
- courses they took at IUM were not offered at their home institutions;
- MiM has shown them different ways of thinking about mathematics;
- it was a wonderful experience to share the time with other math students, to develop friendships and work relationships with math students from all over North America. Many alumni are still in touch with some of their acquaintances from Moscow, both Russian and American.

Several former MiM students joined the Master of Science program in Mathematics offered by HSE Faculty of Mathematics. In fact, MiM keeps playing a major role in recruiting the best mathematics students to HSE. For example, 2 out of 3 international MSc students who entered this year have MiM experience. We see two main reasons for such a strong recruitment effect: firstly, students like the program and want a kind of continuation; secondly, students get a general idea that living in Moscow is a rewarding experience. Unfortunately, although the MSc program at HSE is advertised widely, and 20-30 international applications for this program are received every year, highly qualified applicants are few, and their information sources are even fewer, MiM being the only stable one.

Andrei Negut, who participated in MiM in spring 2007 as a Princeton junior, wrote in 2010: "Math in Moscow was a great experience for me as an undergraduate, but also as a future mathematician. Not only were the courses very interesting and well-taught (on a par with my undergraduate institution, Princeton), but I also met there a number of great mathematicians who taught me new fields and with whom I later coauthored several papers. I would recommend MiM and IUM to all my friends."

Mathematical Higher Education in St. Petersburg: Challenges and Prospects

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St. Petersburg mathematical school has always been held in high esteem. Even though it has already been long since the center of mathematical life in the country relocated to Moscow, St. Petersburg remained the leader in many areas both within fundamental and applied mathematics. In the 1990s, however, the situation worsened: many mathematicians left the country, which affected the quality of mathematical education. Below we discuss the recent attempts to change the situation.

Mathematics students at St. Petersburg State University (SPbSU) are usually introduced to what it is like to do research at a relatively early stage. Students choose an advisor in their second or third year already and start attending seminars dedicated to a specific research area. Despite obvious benefits, such an early specialization might lead to "tunnel vision" and lack of familiarity with even the most basic of terms that are used in other fields. There are several factors that worsen the situation even further:

- SPbSU Department of Mathematics and Mechanics is situated far from the city's other mathematical centers;
- mass brain drain of the 1990s (which affected St. Petersburg much more than Moscow) has led to lack of qualified faculty and, therefore, fewer available courses that would cover many aspects of modern mathematics;
- students are struggling financially and often have to work after classes, which impedes educational process.

The same could be said about graduate students too, who go even deeper down into their very narrow, very specific field of research (often imposed by their advisors). As a result, we get a pool of specialists who know little outside their own field and who aren't integrated into the international mathematics community, which, in the end, brings them even further away from the world of modern science. Moreover, some mathematical disciplines that used to be well-represented in St. Petersburg too are on the brink of extinction.

We will discuss three projects, all of which have been implemented within the past decade. They were aimed at solving the above-mentioned problems and creating an interesting and stimulating environment that would let senior undergrads and graduate students learn more about modern mathematics by inviting the best international experts to give lectures and organize workshops.

The first such project was called the Physics & Mathetmatics Club (PMC) at the St. Petersburg branch of Steklov Institute of Mathematics of the Russian Academy of Sciences. The idea behind it belongs to A.S. Losev of the Institute for Theoretical and Experimental Physics, and it was brought to life by N.E. Mnev of Steklov Institute. PMC was launched in fall 2004. The quality of fundamental education the sphere of physics and mathematics was very much under scrutiny in St. Petersburg in the early 2000s. The problems were caused both by mass emigration of the 1990s and questionable organizational decisions (e.g., when SPbSU Departments of Physics and Mathematics were moved outside city center to the Peterhof campus). Nevertheless, thanks to the fact that there were still a few good schools in St. Petersburg and to the fact that many families were traditionally highly committed to giving their children a good education, there always were quite a lot of mathematically-gifted young people. By their third year at university, those of them who had chosen fundamental subjects would realize that they weren't satisfied with the quality of teaching. Therefore, it was necessary to create an (informal) space where such students could learn more about modern science, namely mathematics and theoretical physics, and get to meet prominent academics.

Yet, even developing a local educational initiative requires new concepts and principles. PMC was guided by the idea of an informal approach to education (following the example of Le Collège de France). Its main principles are: the classes are free and open for everyone, there are no obligatory exams, the lecturers present broad material of a relatively high level. In the 1960s, there used to be a similar club at SPbSU Department of Mathematics and Mechanics, called "Advanced Studies Course for Engineers". PMC was an informal organization too, where self-management was stimulated; students were encouraged to be independent and to organize workshops themselves. Such activities could be more or less successful, depending on the year, but that is exactly how affinity groups develop. The most active students were rewarded financially: they were paid for organizing seminars and got funding to participate in international summer schools. They also organized their own summer schools together with the Institute for Theoretical and Experimental Physics, St. Petersburg Nuclear Physics Institute, and the International University of Moscow. There has been a number of joint summer schools together with Kiev Institute for Theoretical Physics, and several specialized summer schools held at Institut des Hautes Études Scientifiques in France (IHES coordinator: Nikita Nekrasov), Weizmann Institute of Science in Tel Aviv (WIS coordinator: Sergey Yakovenko), and the Chinese Institute for Advanced Studies in Shanghai. In 2006–2011, PMC enjoyed ample funding due to the help of the Russian Academy of Sciences and Dynasty Foundation, so a lot was going on: around 50 advanced courses per year and numerous seminars and colloquia were given by lecturers coming from Moscow or from abroad. The club's approximate attendance rate was between 200 and 300 people. On the whole, we can say that PMC was a success: it has helped a new generation of talented students to learn more and accomplish more in their chosen field. Nowadays PMC is only funded through moderate private donations, and is folding its operations, though it would've probably remained useful.

In 2010, Chebyshev Laboratory began to slowly take over the functions of PMC. It's an interdisciplinary research lab created at SPbSU in December 2010 by the Fields Medal winner Stanislav Smirnov within the "megagrant" framework of the Russian government. The lab conducts interdisciplinary research that covers mathematical analysis, algebra, probability theory, mathematical physics and other areas. One of its priorities is to engage undergraduate and graduate students into research. Besides that, the lab also organizes:

- workshops and seminars on a wide number of topics within modern mathematics (about 100 a year);
- presentations by leading international scholars (over 50 visitors a year);
- conferences and schools for students (about 10 a year).

The lab also supports young scholars (including senior students) financially, which allows them to participate in conferences and summer schools both in Russia and abroad.

The lab's staff are relatively young and very active: the number changed between 40 and 50, with the average age below 30; they publish more than 100 articles and working papers per year. In 2013, JSC Gazprom Neft started to support Chebyshev Lab as part of its social investment program. Students and young PhDs with outstanding performance receive Gazprom Neft scholarships. In 2014, the lab also received a grant from the Russian Science Foundation, and its members regularly win personal research grants and prizes.

In 2007, a club similar to PMC was founded, called Computer Science Club (CSC). Its aim is to introduce students to different aspects of computer science. CSC organizes lectures that cover both fundamental topics (often related to the computational complexity theory) and applications domain. The lectures usually take place during weekends and are free for everyone, no sign-up required. The club is funded by Anton Likhodedov of Deutsche Bank and Yuri Bogdanov of Rigmora Holdings. So far, over 100 courses (consisting of least 10 lectures each) have been read at CSC. They were taught, among others, by leading scientists from Russian universities and research centers, as well as by colleagues from the University of Oxford, University of Warwick, European Bioinformatics Institute, and University of Bergen, and by the representatives of Microsoft Research, Yahoo Research, etc.

In 2011, Computer Science Club became part of Computer Science Center, which was organized together with the School of Data Analysis and the Academy for Modern Programming. The center offers 2- or 3-year-long onsite courses; the classes usually take place in the evenings. The students can get a diploma in one of the three areas: Computer Science, Data Mining or Software Engineering. Core courses include: discrete mathematics, asymptotic analysis, algorithms and data structures, C++, Java, computational complexity theory, databases, computer architecture, concurrent programming, compilers, game theory, image analysis, machine learning, etc. Besides that, the students have to complete experimental projects and to do research. There is no tuition fee but the admissions process is very selective. The call for applications is announced once a year. The center is funded by JetBrains and Yandex, as well as Anton Likhodedov and Yuri Bogdanov.

All the three projects have been very successful in supporting mathematics in St. Petersburg and have helped downplay the negative developments discussed at the beginning of this paper.

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Mathematical Competitions for University Students: Experience of Moscow Institute of Physics and Technology

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In this paper I will give an overview of mathematical Olympiads (academic competitions) for university students based on my experience at Moscow Institute of Physics and Technology (MIPT). This overview will consist of two parts. I will start with explaining the notion of a mathematical Olympiad and naming usual pros and cons for the concept of a mathematical Olympiad for university students in general. Then I am going to give particular details about the experience of MIPT and different mathematical Olympiads at MIPT and abroad.

I will not distinguish between the terms "Olympiad" and "competition". By an Olympiad I mean a written test consisting of mathematical problems, resulting in sorting the students by their accomplishments and awarding them certificates, medals or prizes. It differs from other tests held at universities, at MIPT in particular, because:

- An Olympiad is not tied to any particular academic course — instead, it covers many undergraduate mathematical courses at a time.
- The problems chosen are relatively hard and are only comprehensible for a small portion of students. At MIPT, this portion is approximately 1% of the students.
- The problems are chosen for their good style and relation to serious mathematics. Exercises in standard techniques are avoided and unexpected ideas are welcome.
- There are no formal consequences after participating in an Olympiad, though informal consequences may be great.

When discussing this topic with my colleagues from Moscow State University (Faculty of Mechanics and Mathematics) or Higher School of Economics (Faculty of Mathematics) I fre-quently hear questions like "Why is this necessary at all?" or "Why are you wasting the students' time instead of just teaching them mathematics?" This means that some explanations are definitely expected here; and I am going to give such. The evident aims of mathematical Olympiads, in my opinion, can be summarized as:

- Bringing together mathematically talented students and making them interact.
- Using advanced-level problems to advertize interesting classical or currently developing topics in mathematics and motivating students for further study.
- Letting students have fun because learning mathematics may seem boring to many of them.

There are some special features of MIPT that make mathematical Olympiads useful there. I am going to give some details. Let me start from the "final destination" of this "Olympic movement" at MIPT: International Mathematics Competition for University Students [1] held every year in Bulgaria. This is the most representative mathematical Olympiad for university students from 1st to 4th year of study; in 2015, it attracted more than 300 participants from more than 70 universities. IMC was established in 1994 by John Jayne, professor emeritus at University College London. At the time, this was a competition mostly between Eastern and Central Europe and former Soviet states. This may seem somewhat narrow but in practice, after IMC expanded in the 2000s to include both hemispheres, it still remains mostly a competition of the former Eastern Bloc countries plus Israel. The reason may be the traditionally deep mathematical education at both school and undergraduate level in these countries. Despite the fact that MIPT mathematical curriculum could be called narrow and old-fashioned, in practice, our undergrads' mathematical training is still better than that at the top-ranking Western universities.

MIPT team has participated in IMC a number of times since 1995, when I myself was one of the contestants and took the first place. Since 2009, our participation is also supported by MIPT rectorate because it is seen as an easy and cheap way to advertise the university abroad. In 2009, our team took the 13th place but once we started going to IMC each year, our results improved significantly, and we now usually finish among the top three. In 2012 and 2013, we even managed to take the first place in the IMC team ranking. The training for IMC and other Olympiads is based on the fact that, besides participating in the already mentioned local Olympiads, students have to do homework. The homework consists of the problems from earlier Olympiads and some nice classical problems. In this homework we try to pay more attention to the areas of mathematics not covered by our curriculum, especially to different sorts of algebra.

When another IMC is coming up, we ask our students to write the solutions in English because at IMC and other international competitions, solutions are to be written exclusively in English, unlike IMO for high school students. Therefore, such competitions also help students get acquainted with mathematical English, which is never taught at MIPT regularly.

I would also like to write about other Olympiad activities at MIPT and give some reasons why they may be useful. MIPT is usually ranked first or second in Russia according to independent benchmarks of the quality of applicants to undergrad programs [5]. So, there is no doubt that MIPT students are of topmost quality. But, unlike Faculty of Mechanics and Mathematics of MSU or Faculty of Mathematics of HSE, MIPT is generally not focused on math; in principle, the students can choose from a wide range of subjects including mathematics (pure and applied), computer science, physics, chemistry, biology, etc. Obligatory mathematical courses are not very deep and mostly cover classical analysis and its branches. All this poses a serious challenge for the professors of mathematics; generally speaking, mathematics has to be actively advertised among the students.

I think it is important to mention some historical facts. MIPT Department of (Higher) Mathematics has traditionally been organizing local mathematical Olympiads every spring, starting no later than 1974. In the years 1974-1990, this competition was step one of the three-stage Soviet mathematical Olympiad for university students, where MIPT team would usually perform well against the leaders from MSU Faculty of Mechanics and Mathematics. Among the Olympiad organizers in the past years were Boris Fedosov, Vladimir Uroyev, Sergey Konovalov, Maxim Balashov, and now myself. More recently, we have started to organize our local Olympiads at the end of every semester, one in December and another one in May. This is convenient both for students because classes are almost over at that time and for professors, who often accelerate end-of-semester exams for students that perform well at the Olympiads.

Our local Olympiads are open to BA and MSc students of all years of study; students from other universities may participate too. Usually there are around 50 participants. Our students also traditionally participate in similar mathematical Olympiads held at Saint Petersburg ITMO in April and at MSU in May.

The problems for our local mathematical Olympiads are collected by several people, including Ilya Bogdanov, Boris Trushin, Oleg Podlipskiy, and Arseniy Akopyan. In fact, MIPT is the headquarters of the Russian Mathematical Olympiad for high-school students and the Russian team for the International Mathematical Olympiad (IMO) [3] and, because of this, MIPT has an appropriate atmosphere, where various Olympiad problems for the school and university levels are continuously discussed and developed.

The students doing best at the local Olympiad have the privilege of going to international competitions in mathematics. Our students usually participate in Vojtěch Jarník International Mathematical Competition [2] in Ostrava, Czech Republic in March or April, and in International Mathematics Competition (IMC) [1] in Blagoevgrad, Bulgaria, held in July or August. The latter has already been described above.

To conclude, I would like to mention some particular students who have performed very well at various Olympiads and are now starting their careers as mathematicians: Pavlo Mishchenko (currently studying at Ecole Normale Supérieure de Lyon), Yakov Kononov, (currently studying at HSE Faculty of Mathematics), and Alexey Balitskiy (currently studying at MIPT and the Institute for Information Transmission Problems of the Russian Academy of Sciences).

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[2] Vojtěch Jarník International Mathematical Competition.
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Changing Traditions of Mathematical Education: BSc Program in Mathematics at the National Research University Higher School of Economics

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HSE Faculty of Mathematics invited its first bachelor students in 2008. The program aims at providing a fundamental mathematical background as well as wide opportunities for its application: from physics, economics and computer science to actuary and financial analysis. Below we describe the problems encountered by the Faculty of Mathematics while building a new mathematical curriculum, and the solutions found. To this end, we first need to recap the principles of mathematical education in traditional Russian universities.

A typical faculty of mathematics in a Russian university follows Soviet tradition dating back to the 1920s–1930s. Students are offered a standard curriculum or a choice between its several standard variations. Each subject within the curriculum is taught in the form of lectures delivered to all students enrolled, and accompanied by recitation sessions conducted separately in smaller groups, which are similar to high-school classes. There are also special topics courses and seminars offered every semester. Individual interaction between students and professors happens mostly in the context of writing bachelor's thesis.

Details and advantages of this traditional framework are described in another text of this issue [1]. However, this scheme turned out to be inadequate for the objectives set by HSE Faculty of Mathematics for the following reasons:

- Study plans do not allow for much variation. Students inclined to pursue an industrial career have no time to specialize, and students planning to stay in the academy cannot intensify their training in fundamental mathematics.
- The mandatory part of the curriculum is hard to modify; it tends to be very conservative, not sensitive to contemporary trends in mathematics.
- Lack of contact between a freshman or a sophomore and a professor obstructs the development of key professional skills (e.g., scientific communication and self-study) and impedes comprehension of abstract ideas.

In order to partially compensate the negative effect of these drawbacks on the most motivated students, some non-government "elite" educational institutions in mathematics and computer sciences were created, including the Independent University of Moscow (IUM) [2], and the Yandex School of Data Analysis (SDA) [3]. These institutions played a decisive role in the foundation of two new faculties within Higher School of Economics: Faculty of Mathematics (FM) and Faculty of Computer Science. Educational programs offered by these faculties were meant to be free of the listed drawbacks.

FM has chosen a format that merges some traits of the Soviet tradition with those of the Anglo-Saxon tradition. This format looks as follows: the first two years of the 4-year BSc program consist of mandatory basic courses, including both those traditional for Soviet mathematical education and "innovative" ones (topology, representation theory, Galois theory). The mandatory curriculum of the last two years is limited to academic writing, history of mathematics, and probability theory. All the rest is an "individual study plan" chosen from a large pool of courses offered by FM, other HSE departments, or external programs (first of all, IUM and SDA).

Mandatory courses are conducted in the form of lectures, tutorials (more resembling the North-American rather than the Soviet ones) and "mathematical practicum" sessions. The latter are individual discussions of theoretical problems between students and instructors; this kind of educational activity follows the best practices of IUM and mathematically oriented high-schools [4]. Optional courses can be basic ("elective courses"), taught in the same format as mandatory courses, or advanced ("special topics courses"), taught in the form of lectures. Thus, there are two major differences that distinguish the new scheme from the traditional one:

- "Mathematical practicum" and coursework for freshmen and sophomores provide intensive student-faculty interaction;
- Juniors and seniors build their own study plans choosing from a large pool of elective courses [5] and adding non-mathematical courses from other departments if desired.
- These features create the following advantages:

- Students who are half-way through their BSc program and decide to concentrate on a particular applied subject may take non-mathematical courses in their chosen field complemented by relevant advanced mathematical courses; these students do not waste their time on mathematical background unnecessary for them personally;
- Students wishing to pursue an academic career may first specialize in their chosen research field, and then, parallel to their own research agenda, strengthen their background in other mathematical subjects;
- FM can dynamically adjust the range and contents of elective courses without touching the mandatory part;
- The range of advanced courses can be expanded without increasing the teaching load: some courses may be offered bi-annually, so that students can take them either in their 3rd or 4th year of study.

As was expected, the rigid, mandatory part of the curriculum turned out to be the most problematic. It was clear that this part should be created from scratch rather than based on the Soviet tradition. Firstly, we had to reduce the contents of a traditional 5-year program to basically a 2-year program while adding new subjects (e.g., topology and Galois theory). Secondly, we had to provide up-to-date teaching materials (most textbooks currently in use at Russian universities are reprints of 50-year-old editions, at best). We also had to deal with internal restrictions imposed by HSE. For example, classroom hours are restricted by HSE regulations, whereas our competitors pose a double or triple amount of classroom hours (compared to what we have at HSE) as their advantage.

For these reasons, it was decided not to fix the mandatory part of the curriculum at the beginning. At the start-up stage (first several years of the program), instructors of mandatory courses all together discussed the prerequisites, core material and its distribution between courses. Timing was favorable for this scheme, since the first students were few, and the first instructors were very experienced (the percentage of young faculty members reached its current record later).

In 2014, the "codification" of the mandatory curriculum began, based on the experience of the previous several years. Teaching materials created during this period are now being unified and rectified. This task is not yet complete but it is already clear that we have obtained satisfactory "experimental" solutions to most of the challenges. A principal — yet unsolved — problem is that of finding an optimal balance between algebra and analysis in the mandatory part of the curriculum. Whether to make certain topics mandatory is being vividly argued upon. As a drawback of HSE educational model (actually, of any "western-type" model), one can view the impossibility of using exams as tools for education rather than only for control. The Soviet tradition implemented this possibility, which, to a large extent, shaped the success of the Soviet mathematical school. For example, at HSE it is forbidden to retake an exam once a student has passed it.

The fine-tuning of the BSc program is close to its completion [6]. FM partially owes its success to its international advisory board (P. Deligne, S. Fomin, A. Okounkov, T. Miwa, S. Smirnov), whose members helped a lot with their expert advice. According to the 2013 report of the advisory board [7], our BSc program is at the level of the best mathematics undergraduate programs in the world (this does not yet apply to graduate programs), and our department is in the top-100 of mathematics departments worldwide (just to emphasize: this estimate is based on personal opinion of the advisory board members rather than on formal quantitative evaluations). On the other hand, members of the advisory board indicate the following issues: lack of small (up to 10 students) study groups, insufficient promotion of alumni's career prospects.

A group of several strong students suggested their own version of the mandatory curriculum. The great job done by these students has provided elegant solutions to many methodological and organizational problems. Either competition with HSE or independent innovation initiatives have led some other institutions of higher education to similar modifications of their undergraduate programs in mathematics. For example, an introductory topology course has been added to the mathematical curriculum at Moscow State University [8].

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Undergraduate Mathematical Education at St. Petersburg State University: Old Traditions and New Developments

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In 2015 St. Petersburg State University opened a new bachelor program in mathematics. While the existing 5-year diploma program had historically been very successful, recently a need to address modern challenges became clear. Below we describe the new program, which keeps the traditions of fundamental education but at the same time offers its students greater flexibility in choosing their educational trajectories.

SPbSU (known as Leningrad State University during the Soviet times) is the oldest Russian university; it boasts a long tradition of mathematical education, dating back to Leonard Euler and Bernoulli brothers. Its professors authored most of the textbooks used in Russian higher education up to the beginning of the twentieth century, and it has educated a great number of well-known pure and applied mathematicians, as well as scientists from other disciplines and engineers over the last 300 years.

Mathematics was originally part of the Department of Physics and Mathematics until 1933, when the Department of Mathematics and Mechanics was created (which also includes astronomy). The now prevalent undergraduate educational system crystallized in the early twentieth century and was more or less the same throughout most Soviet universities. It relied on a rigid system of mandatory courses given over a period of 5 years, after the completion of which students would receive their higher education diplomas. During the third year, students would write a term paper and choose a chair to be associated with, which would in the end influence their diploma thesis topic as well as the choice of the only four optional courses they could take.

While at the first glance the system seems to be very rigid and has a number of drawbacks, it used to be highly successful at SPbSU (and its Moscow counterpart Moscow State University) due to the following reasons:

- Mandatory courses were covering most of the mathematical areas at a fairly deep level, and graduating students were getting a much more solid and universal background than many of their peers abroad.
- While the system itself was rigid, the curriculum was regularly updated in an attempt to cover modern developments. E.g., SPbSU was one of the first world universities to include some new subjects, like Lebesgue integration, and — later — functional analysis into its curriculum.
- Small number of optional courses was compensated by an abundance of informal seminars and discussion groups, with students learning as much in the evenings as during the daily lectures.
- The high level of both faculty and students ensured good educational level. They were in close contact, and students were actively involved in scientific research.
- There were strong connections to applied disciplines, with many professors (notably Leonid Kantorovich) working both in pure and applied mathematics.

Though quite successful for a long time, the system had, nevertheless, several serious drawbacks:

- Emphasis on lectures rather the seminars led to lack of feedback from students.
- Rigid division into chairs forced many students to choose their specialization too early, thus limiting their education.
- At some point, existing chairs stopped covering all the aspects of modern mathematics, leading to gaps in curriculum.

In the 1970s, the Department of Mathematics and Mechanics moved from city center to the Peterhof campus, which created many problems. At the new location informal courses and seminars, which used to run until midnight, practically disappeared, as transit consumed much more time. This also coincided with the system becoming more bureaucratic and rigid, and the curriculum became almost frozen in time, lagging behind modern mathematics.

In the late 1980s, a group of mathematicians from SPbSU and the St. Petersburg branch of the Steklov Mathematical Institute of Russian Academy of Sciences (PDMI) addressed many of the problems by organizing so-called "PDMI classes" for undergraduate students, which provided alternative versions of the mandatory courses. Systematic approach was applied to revising and modernizing the curriculum. Moreover, most lectures were held at PDMI building in city center, so the students had regained easy access to seminars. Many of the courses were taught by PDMI researchers, expanding the choice of areas covered and raising the students' academic level.

This significantly improved the situation for the next decade, effectively resolving many problems. However, the rigid chair structure remained, and many professors left the country, which led to poorer choice of courses and topics. Moreover, due to bureaucratic problems, PDMI classes had to function as an unofficial structure, essentially forcing students to take all the exams twice. In the end, students were left with a curriculum that needed revision and a much smaller choice of additional courses to take or professors to work with. To complicate things, the rigid 5-year program was hardly compatible with the Bologna Declaration, limiting options for student exchange.

Soon it became clear that undergraduate mathematical education in St. Petersburg was in urgent need of revision in order to achieve compatibility with international standards for bachelor-level education. One could argue that the old comprehensive system works better for talented students, provided they are given access to many optional courses. However, it seems that the current realities are such that most students just do not have enough time to follow many additional courses and seminars, thus a once perfect system has become too rigid and restrictive.

Different approaches to the problems were discussed and in the end, it was decided to revitalize PDMI classes, while the university overall was shifting towards the Bologna system of 4-year undergraduate education. A new program opened in 2015 (with the classical one still running).

The new undergraduate program is still a work in progress but we strive to adhere to the following principles:

- **Flexibility of education**

The mandatory part of the curriculum has been reorganized and modernized, having been reduced to roughly one half of the total number of courses throughout 4 years of the program. They now amount to 100%, 66% and 33% of the courses during the first three years respectively. Basic courses cover all fundamental disciplines at a level allowing for further studies. A gradual introduction of optional courses together with personal mentors will allow students to pick their individual educational trajectories consciously, in a way that suits their personal needs.

- **Multitude of future careers**

It is no longer assumed that all the graduates will become professional mathematicians; on the contrary, a variety of mathematics-intensive careers is now recognized. Already, a Theoretical Computer Science option was created, one of the first in Russia. The individual trajectories can lead to employment in applied fields or towards graduate-level education in mathematics or other disciplines, fulfilling the modern need for multidisciplinary researchers. SPbSU and PDMI plan to offer a wide range of optional courses, and we intend to develop collaboration with institutes and enterprises in order to create specialized courses in applied mathematics, thus expanding our students' career prospects.

- **Integration with research**

The new bachelor program will keep the old traditions of early introduction to research work through collaboration with PDMI and Chebyshev Laboratory of SPbSU. A more problem-oriented approach to course development has been adopted. Furthermore, students will have a chance to participate in workshops and conferences, as well as exchange programs.

Much planning and energy has been spent on creating the new program and attracting good students. An advisory board of prominent mathematicians from St. Petersburg and elsewhere was created to steer the program. Last but not least, classes have been moved back to city center, leaving students more time for seminars and cultural life. Of great help was one of the Russia's leading companies, JSC Gazprom Neft, which has made it possible to attract talented school graduates from various Russian regions and has extended financial support to a significant number of students. Suffice to say, more than half of the 45 places available at the program in 2015 were occupied by the winners of various academic competitions for high-school students (usually referred to as Olympiads), many of them coming from provincial schools. Moreover, the program has attracted more winners of the national Mathematical Olympiad than any other undergraduate mathematics program in Russia.

We are sure that the new program will be as successful as the previous ones offered at SPbSU. The first year saw 45 students — almost double compared to the old program. In 2019 (i.e., when the first class graduates), SPbSU is expected to open a master's program in mathematics with eventual instruction in English.

For notes

About HERB

Higher Education in Russia and Beyond (HERB) is a quarterly informational journal published by National Research University Higher School of Economics since 2014. HERB is intended to illuminate the transformation process of higher education institutions in Russia and counties of Eastern Europe and Central Asia. The journal seeks to adduce the multiple-aspect opinions about current challenges and trends of regional higher education and give examples of the best local practices. Our audience represents wider international community of scholars and professionals in the field of higher education worldwide. The project is implemented as part of cooperation agreement between Higher School of Economics and Boston College Center of International Higher Education.

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