S C I E N C E & T E C H N O L O G Y P O L I C Y I N S T I T U T E

Russia Space Talent

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Executive Summary

In 1957, the world watched in awe as the Soviet Union launched Sputnik into orbit. The space program has been one of its greatest achievements since the Second World War and a source of inspiration and pride for generations of Russians. After the collapse of the Soviet Union and the turmoil that followed, the space program experienced a string of embarrassing technical failures and multiple reorganizations. Nevertheless, Russia remains one of the leading spacefaring nations. While Russian scientists and engineers are a critical asset of Russia's space industry, few studies have examined the development and utilization of its space talent.

The IDA Science and Technology Policy Institute (STPI) sought to fill this gap. Specifically, STPI set out to answer the following questions:

1. What research institutions in Russia support the space sector? On what specific areas, specialties, or degrees do they focus? What partnerships, domestic or foreign, do these institutions have?
2. What space sector academic programs and research institutions have high publishing rates and citation indices?
3. To what extent is collaboration with other regions of the world an important factor in attracting and retaining talent?
4. What pathways exist for talent to enter the Russian space sector? Where do trained students go after completing their degrees?

The study drew on several open sources in English and Russian languages. These included: (a) a review of the literature about the education system in Russia, brain drain and other challenges in the space sector, the quality of students' preparation in Russia and other countries, and other pertinent topics; (b) quantitative analyses of the educational and employment statistics compiled by the Russian government; (c) bibliometric analysis of space-related journals in Web of Science from 2005 to 2021; (d) interviews with two key informants; and (e) case studies of 15 institutions that play an important role in preparing for and employing space talent.

STPI encountered some challenges in conducting the study. The first one stemmed from the deterioration of the political situation in Russia that began with the annexation of Crimea in 2014 and culminated in the invasion of Ukraine in 2022. Our team discovered that some information about the space sector in Russia had become restricted—most consequentially, the websites of several organizations within Roscosmos (Russia's space agency) were inaccessible. In addition, the Russian government issued a decree in 2021 that barred its citizens from sharing certain information about the space sector. This edict not only explicitly covered some key information about Roscosmos that our team needed, but it also led to a decision to abandon the plan to interview space scientists and engineers based in Russia, as it could put them in danger. Other challenges in conducting the study included a rapidly changing situation in Russia with respect to its workforce precipitated by the invasion of Ukraine; absence of explanations for how the educational and employment statistics are collected by the government and what certain variables meant; and lack of validated taxonomy for classifying educational programs as space or space-adjacent, which was needed to determine the size of the workforce in these fields.

The answers to research questions posed for the study are presented below.

1. *What research institutions in Russia support the space sector? On what specific areas, specialties, or degrees do they focus? What partnerships, domestic or foreign, do these institutions have?*

Using several sources, STPI identified 74 organizations that play an important role in developing and employing talent in the space sector. The list includes universities (located primarily in Moscow and Saint Petersburg but also other regions of the country), research institutes within the Russian Academy of Sciences (RAS), and several research and development (R&D) units within Roscosmos. STPI examined 15 of these organizations (7 universities, 5 research institutes, and 3 industry organizations) in more detail. Analysis of websites revealed that all universities offered programs in space and space-adjacent fields, with the number of slots totaling a few thousand per year across degree levels. These programs covered a range of science and engineering fields, including aircraft design, navigation systems, remote sensing, propulsion, space instrumentation, aerodynamics, missile systems, astronomy, astrophysics, and space biology/medicine.

Review of university websites and published literature revealed acquisition of practical skills as an integral part of student preparation starting at the undergraduate level. Special organizational structures called *base kafedras* had been established at top universities to facilitate connections between training and employing institutions. For example, at Bauman Moscow State Technical University—one of the most prestigious educational institutions for space scientists and engineers—5 of 11 programs in space fields are immersion programs, which require undergraduates to work at Bauman's partner organizations (such as Roscosmos) throughout the duration of their studies.

It was more difficult to understand the role of international partnerships in student education and professional development. While websites of many universities and RAS research institutes listed foreign universities as partners, the status, nature, and extent of these relationships was impossible to determine. Analysis of publication co-authorships revealed that the most common collaborating countries for the 15 institutions were the United States, Germany, the United Kingdom, France, and Italy. However, these data offer no insights on the role of these collaborations in talent development or attracting students to the space fields.

2. *What space sector academic programs and research institutions have high publishing rates and citation indices?*

STPI identified 23,097 English-language publications in space-related journals that listed a Russian institution for author affiliation (of over 450,000 total publications). Analysis of this dataset showed that the total number of publications per year with a Russian author more than tripled over the last decade, to just over 3,000 in 2020. Further, 42 percent of these publications included a foreign co-author, although the fraction of co-authored papers declined from the peak of 52 percent in 2010 (corresponding to the resurgence of the Russian space sector after the collapse of the Soviet Union) to 37 percent in 2021. Nearly 60 percent of papers with a foreign co-author were in astronomy and astrophysics. The most common collaborating countries that emerged from this analysis were the same as for the 15 case study institutions. Papers with a foreign co-author garnered significantly more citations than papers with Russian-only authors.

Moscow State University had the most frequent publication output, with 15 percent of all papers including an author with this affiliation; Saint Petersburg State University was a distant second with 5 percent of papers. It is important to note that nearly 10,000 of the approximately 23,000 papers, or about 40 percent of the total, were excluded from the institution analysis because they listed RAS as an affiliation, not a specific institute within it. It is probable that some RAS institutes focused on space (in particularly the Institute for Space Research) would also have emerged as publication leaders along with Moscow State University.

3. *To what extent is collaboration with other regions of the world an important factor in attracting and retaining talent?*

It was not evident from the research that there is a clear role of international collaborations for attracting and retaining talent. As mentioned earlier, 42 percent of publications in space journals had a foreign co-author, and partnerships with the international scientific community were especially strong for astronomers and astrophysicists. In addition, analysis of enrollment data showed that pathways exist for international students to be educated at Russian universities. However, the number of such students has always been relatively small (7 percent in 2021) and limited primarily to countries from the former Soviet Union. It could not be determined whether these international students remain in Russia after graduation or return home and engage in partnerships with Russia.

The invasion of Ukraine has already disrupted many of these relationships and it is unclear whether and when they will be restored. While it was difficult to determine to what extent foreign partnerships are important to attracting students, some top universities advertised programs and activities that involved trips abroad, joint degrees, and other interactions with foreign countries—presumably serving as a recruitment tool. In addition, several papers discussing shortages of space talent identified restrictions on foreign travel as a deterrent for young people interested in entering the profession. The available evidence suggests that the loss of connections to international partners will have a negative effect on the Russian space sector, both in attracting talent and in the quality of scientific research.

4. *What pathways exist for talent to enter the Russian space sector? Where do students go after completing their degrees?*

Figure ES-1 shows the educational and employment pathways in the Russian space sector, which is similar to the United States in its broad outlines. In brief, the pre-college phase begins at age 7 and is divided into elementary (grades 1–4), basic (grades 5–9), and middle (grades 10–11) education. Several highly competitive high schools, most famously Kolmogorov Boarding School specializing in physics and mathematics, supply students to top universities in Russia, serving as an entry point to various professions, including space (60 percent of Kolmogorov graduates go to Moscow State University). Students who wish to pursue higher education can enroll in undergraduate studies to earn a bachelor's or specialist degree (4 years and 5–6 years in duration, respectively), both of which qualify students to enter a master's program (2 years).

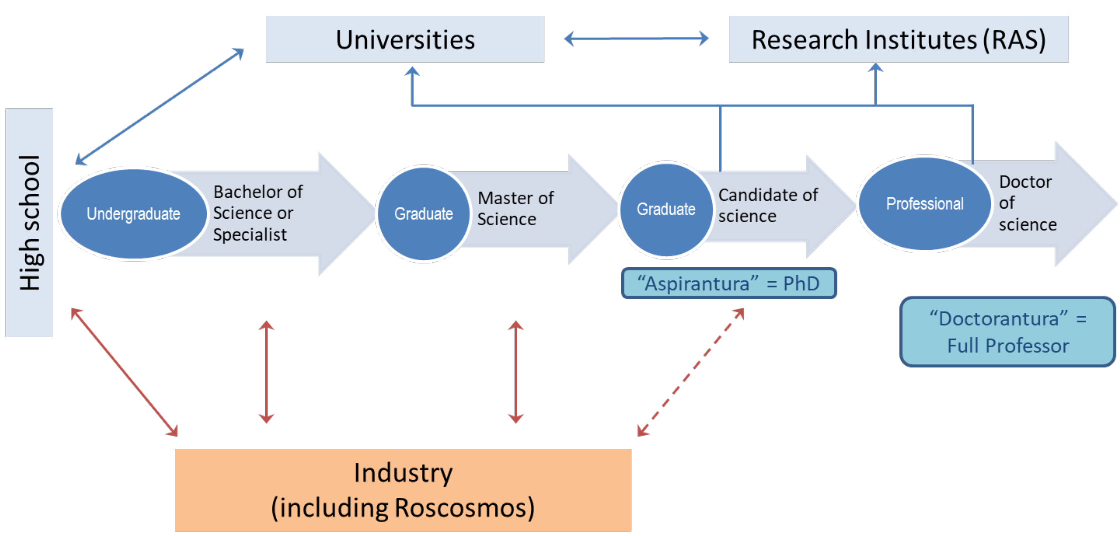


Figure ES-1. Education Pathways in Russia

In 2003, Russia began a partial transition to the European degree structure, commonly termed the Bologna process, the main result of which was the addition of a 4-year bachelor's degree as a parallel track to a traditional specialist degree. In contrast, Russia has retained a two-tier qualification schema for higher degrees. The first stage is the candidate of science degree (*aspirantura)*, which takes 4 to 5 years to earn and is generally accepted as the U.S. PhD equivalent. The second stage is the doctor of science degree (*doctorantura*), which is the highest professional qualification that requires at least 10 years of full-time research to produce a body of independent scholarship. In 2021, approximately 350 of the nearly 15,000 advanced degrees, about 2.5 percent, earned a doctor of science title.

The space ecosystem in Russia is an interconnected network of universities, RAS institutes, and Roscosmos R&D units with talent moving between them. According to one source, it is difficult to obtain a position at Roscosmos "off the street;" the path to this largest employer in the space industry lies through high school recruitment programs and college practicums. Based on limited information, STPI inferred that Roscosmos, several RAS research institutes, and universities are the main employers of talent in the space sector, but no data were available on employment numbers, desired qualifications, staff turnover, and other trends.

Narrow specialization and limited options to change career direction in any field are an enduring legacy of the system where supply and demand for workers was tightly controlled by the state. Some scholars believe this prior strategy for developing talent remains a weakness of the Russian system in a more competitive post-Soviet environment. Consistent with this view, a few studies that compared Russian science, technology, engineering, and mathematics (STEM) students to peers in China and the United States found that they were weaker in critical thinking, mathematics, physics, and computer science skills. And despite a concerted effort by the Russian government to improve the international rankings of educational institutions, only Moscow State University is occasionally listed in the top 100.

Using official Russian government data, STPI analyzed workforce trends in STEM fields and the space sector specifically. A consistently negative pattern emerged for workforce size and the training pathways needed to sustain it. The total number of R&D workers decreased from 740,000 to 680,000 (8 percent) between 2010 and 2020. The supply of talent was also compromised: the number of graduates with undergraduate and master's degrees declined from 1.3 million in 2013 to 800,000 in 2021 (37 percent). The number of graduates in space and space-adjacent fields, which comprise 14–20 percent of the total depending on the year, also decreased—by 9 percent in space plus adjacent fields and by 30 percent in space fields alone. Consequently, in recent years no more than 4,000 students per year have obtained undergraduate and master's degrees in space fields. For advanced degrees beyond a master's degree in space fields, about 900 individuals earned a candidate of science degree per year and 2 individuals earned a doctor of science degree.

In addition to producing fewer STEM workers, Russia has experienced significant brain drain that began with the fall of the Soviet Union and continues to this day. Russian officials are aware of this problem: for example, the president of RAS said in 2021 that the number of scientists who left Russia has increased from 14,000 in 2012 to 70,000 in 2020. A Russian scholar reported in a paper published in 2014 that half of the organizations in Russia's defense industry were experiencing shortages of workers. The space industry was estimated to require 100,000 highly skilled workers by 2025, but based on our analysis of the government's statistics on degree production, Russia will not be able to meet this demand—even with no further brain drain.

Contents

1. Introduction

A. Background

Global innovation is driven by science, technology, engineering, and mathematics (STEM) talent. A healthy innovation ecosystem relies not only on research funding, a vibrant business system, and cutting-edge research infrastructure and tools for discovery, but also on innovative, hardworking, and highly skilled STEM talent. It is the people who transform ideas and concepts into new products and services. A highly skilled STEM workforce is often viewed as a crucial national asset that pushes boundaries and educates the next generation of leaders in science and technology.

Russia and the United States pioneered space exploration. The world watched in awe as the Soviet Union successfully launched Sputnik in 1957. From the 1960s to the early 1990s, the Soviet Union, followed by Russia, and the United States advanced space science and exploration, inspiring generations of scientists and engineers. Rapid advances can be attributed to funding, but it is the scientists and engineers who advanced space technologies and made space exploration possible.

Soviet scientists were well regarded in mathematics, engineering, propulsion, astronomy, and other fields that underpinned the Soviet Union's successes in space. After the fall of the Soviet Union, Russia's space program went into a period of decline, but since the early 2000s, it has enjoyed a period of renewed investment. Russia remains one of the leading spacefaring nations—no doubt in part due to its skilled space workforce.

Space topics pertaining to Russia have been widely studied and researched, but few studies attempt to understand the skills, workforce, and people needed to maintain or grow Russia's space industry.

B. Introduction

The IDA Science and Technology Policy Institute (STPI) conducted this study to examine the development of space talent in Russia who fuel and support its space sector. STPI set out to answer the following research questions:

1. What research institutions in Russia support the space sector? On what specific areas, specialties, or degrees do they focus? What partnerships, domestic or foreign, do these institutions have?
2. In Russia, what space sector academic programs and research institutes have high publishing rates and citation indices?

3. To what extent is collaboration with other regions of the world an important factor in attracting and retaining talent?
4. What pathways exist for talent to enter the Russian space sector? Where do trained students go after completing their degrees?

C. Methodology

STPI used a mixed methods approach to address these research questions. First, we conducted an in-depth literature review in both Russian and English on how the Russian educational system has changed over time, the composition and size of Russia's STEM workforce and, more specifically, the Russian space workforce. The literature review included research papers on the Russian space workforce as well as news articles describing changes in that workforce. The goal of the literature review was to understand changes in the Russian educational system since the fall of the Soviet Union, identify the most important training and employment institutions, collect data on the quality of preparation in STEM fields, and document challenges to Russia's research and development (R&D) ecosystem.

We also conducted quantitative analyses of Russian education statistics as well as global statistics on expenditures on space and on Russian scientists and engineers. We used reports from the Russian Ministry of Education on graduates by specialization. STPI coded hundreds of academic specializations into four categories: space, space-adjacent, other STEM, and non-STEM categories using the U.S. Department of Education's Classification of Instructional Practice as a guide. For example, aviation and rocket science, ballistics, and geodesy were coded as space; aircraft engines, mathematics, and informatics as space-adjacent; biology, architecture, and geography as other STEM; and design, journalism, and jurisprudence as non-STEM. Social sciences and medical specialties were combined with non-STEM fields. This coding enabled STPI to gauge the number of graduates with different degrees in space-related fields versus all fields.

We used publications rates, citations, and co-authorships from Russian institutions as proxies for the research output, quality, and collaborations of Russian space scientists and engineers. To perform these analyses, STPI analyzed all publication records available from Web of Science for 112 journals and 51 conference proceedings in space and space-adjacent fields (based on the titles and descriptions) from 2005 to 2021.

The research relied on interviews with a few experts, web searches about Russian academic institutions, as well as news articles and reports regarding the academic standing of the institutions.

Finally, STPI conducted case studies of 15 institutions that play an important role in the Russian space sector, chosen in collaboration with the sponsor. The sample was purposively chosen to include three types of entities important to the space sector in Russia:

universities (n=7), industry organizations (n=3), and research institutes (n=5). Data for case studies were obtained from interviews with a few key informants, organizations' websites, publications, news articles, and reports.

D. Caveats and Limitations

The study had four limitations. First, due to the worsening political situation in Russia, access to information about its space sector became restricted over the past 2 years. In October 2021, the Russian government issued a decree that any Russian national who shares information on domestic space activities with foreign citizens can be designated as a foreign agent (Reuters 2021). The scope of this restriction included much of the information on Roscosmos, including its financial status, problems, and plans. This decree prevented STPI from contacting the individuals knowledgeable about the space sector who live in Russia, as speaking with us could put them in danger. At the time of the research for this report, some Roscosmos websites were not accessible.

We relied on Russian government data accessed from the Russian Statistical Service to understand trends in education in Russia, but the data available did not contain any codebooks or explanations for how the data were collected and aggregated. Consequently, large fluctuations in the data from year to year could be due to a change in methodology, actual variation, or both—but STPI could not determine which of these was the case.

Also, STPI's intent for the case studies of key organizations involved in educating and employing space talent was to collect information on foreign partnerships, number of faculty and research/teaching staff, non-degree granting programs, position descriptions, alumni destinations, and K-12 programs related to space. However, this information was not available consistently and the search had to be limited to a smaller number of variables. Finally, as discussed in the methods, STPI coded training specialties as space, space-adjacent, or other STEM based on their titles. This coding is somewhat arbitrary, as no broadly accepted taxonomy currently exists for the space sector.

E. Organization of Report

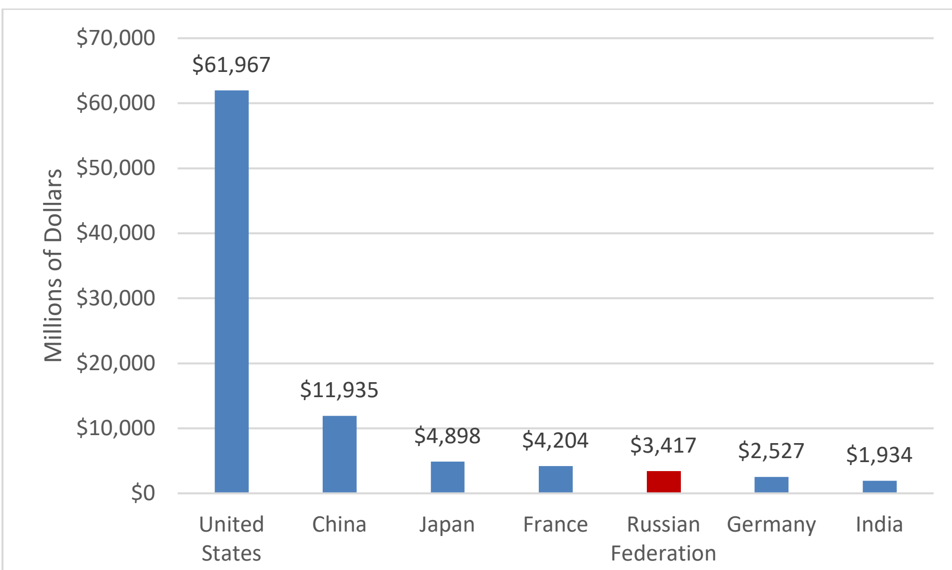
The report is organized into six chapters. Chapter 2 compares the Russian space sector with those of other spacefaring nations. In Chapter 3, we provide an overview of Russia's educational system and describe its role in the development of Russia's space human capital. Chapter 4 describes the environment for space R&D for Russian scientists and engineers. Chapter 5 describes the education and training of the space STEM workforce. Chapter 6 offers overarching findings and conclusions about the Russian space workforce.

2. International Benchmarking

This chapter compares Russia to other spacefaring nations in terms of expenditures on space and human capital in STEM. This information helps contextualize the system for which space talent is being nurtured and developed.

A. Global Space Budgets

Since 1957, 89 nations have launched at least one spacecraft, with many of these countries' first forays into space taking place in the 1990s and 2000s (DoD 2022). Despite this long list, in 2021 the United States, China, Japan, France, and Russia had the largest government expenditures on space programs in the world (Euroconsult 2021), with the United States significantly outspending the other countries (Figure 1). In that year, Russia placed fifth of seven in expenditures, at $3.4 billion, after the United States ($62.0 billion), China ($11.9 billion), Japan ($5.0 billion), and France ($4.2 billion). Russia's total expenditures on space in 2021 were lower than in 2018 ($4.6 billion), which was already down sharply from 2013 ($9.8 billion, Euroconsult 2022).

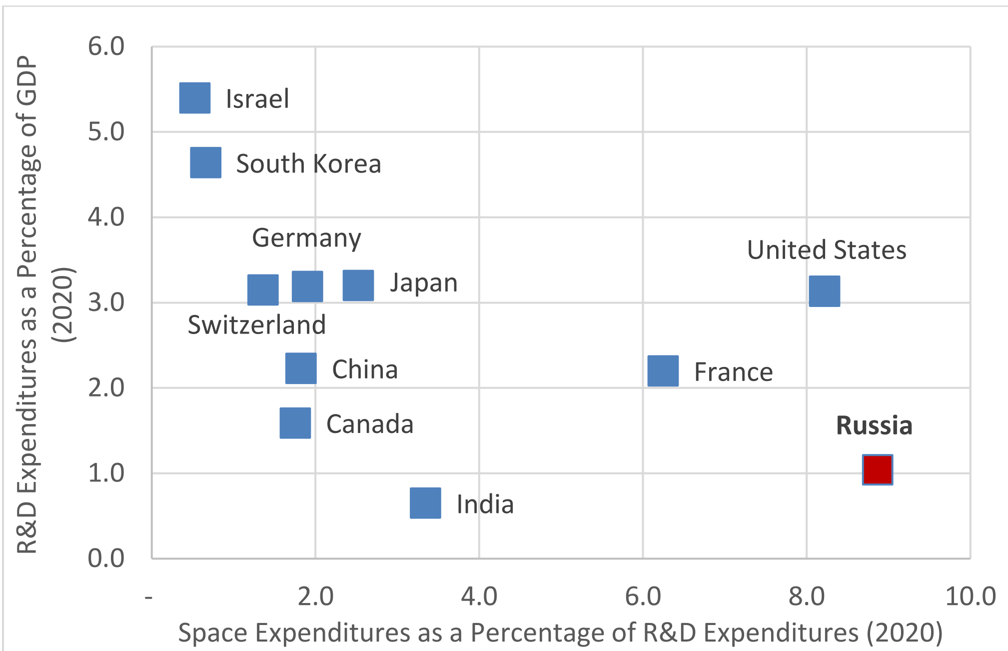


Source: Euroconsult 2022—Government Space Programs Report

Figure 1. Space Expenditures in Millions, Select Countries, 2021

Another way to gauge a government's commitment to the space sector is to calculate the percentage of a nation's total government expenditures that is allocated to space. R&D

expenditures normalized by their share of gross domestic product (GDP), often referred to as R&D intensity, provide a useful measure for making international comparisons. According to the literature, an R&D intensity over 3 percent is viewed as high and reflects substantial investment in innovation (NCSES 2022). Figure 2 shows the space expenditures as a share of R&D intensity for the most prominent spacefaring nations. Based on these data, Russia's space expenditures as a percentage of its overall expenditure on R&D was the highest among these countries, at nearly 9 percent in 2021, although Russia's R&D intensity is among the lowest. These data show that while Russia is committing relatively few resources to R&D, space remains a national priority.

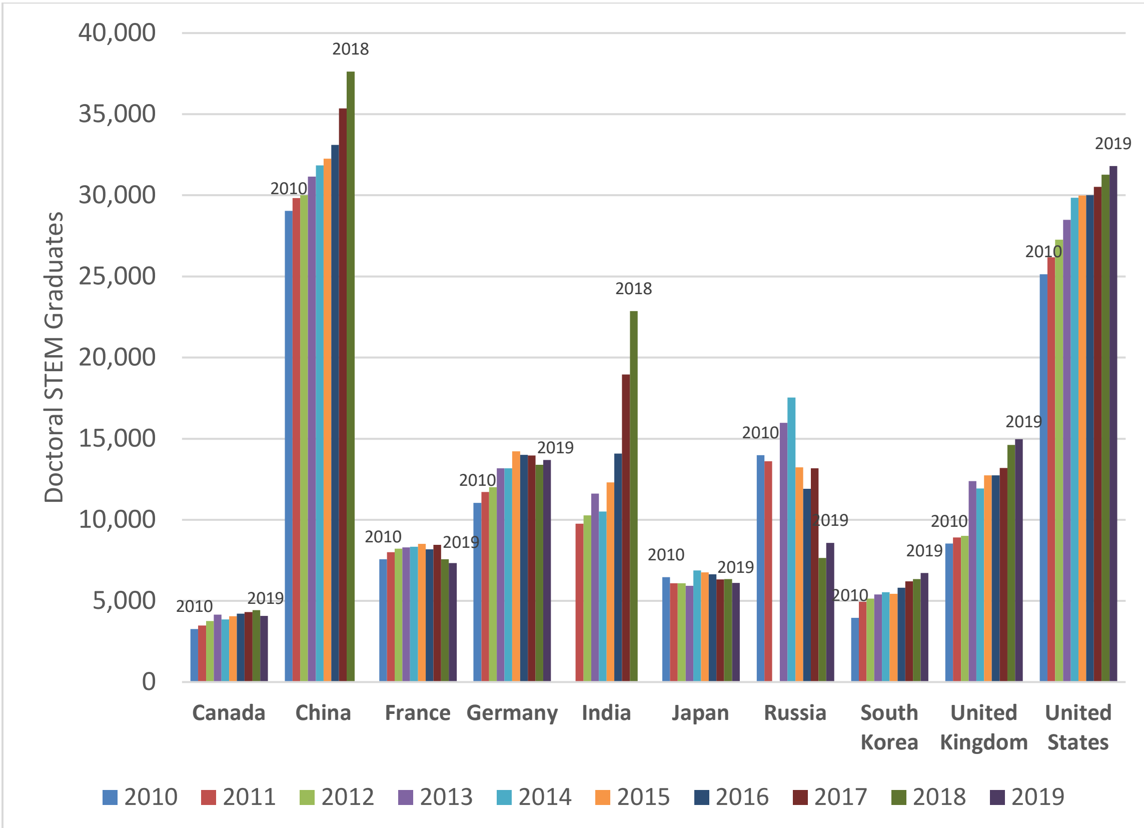


Source: STPI analysis based on Government Space Budgets from Euroconsult, OECD data on R&D expenditures and GDP.

Figure 2. Government Space Expenditures versus R&D Intensity

B. Global Graduations of Students with STEM Degrees

This section compares STEM doctoral degrees awarded by selected spacefaring nations. STEM doctoral degrees include degrees in the physical sciences, the biological sciences, mathematics, statistics, computer science, agricultural sciences, and engineering. In this definition, STEM degrees do not include those in the social sciences. This section does not focus on space-specific degree fields only. We use trends in awards of STEM degrees as a proxy for space fields. Figure 3 shows that between 2010 and 2019 STEM doctoral degrees increased in many spacefaring nations, with particularly sharp increases in China and India. The United States, the United Kingdom, and South Korea granted more STEM doctoral degrees as well. STEM doctoral degrees granted in many of the other nations were flat, with Russia reporting the largest overall decline in the global percentage of STEM doctoral degrees awarded between 2010 and 2019. More specific data for Russia is presented in later chapters, but Figure 3 allows for comparisons across countries.



Source: Science and Engineering Indicators, Table SHED-12

Note: Data for 2019 downloaded from OECD.Stat; Eurostat, Education and training database

Figure 3. Number of Doctoral STEM Graduates from 2010 to 2019 for Select Countries

We also examined the share of doctoral degrees awarded in STEM fields out of total doctoral degrees awarded. The percentage of doctoral degrees awarded in STEM fields is a rough proxy for the potential for innovation in science and technology topics. Figure 4 shows trends across select spacefaring nations. Over time, these percentages have been relatively flat for any given country; India is the only country that has reported a significant increase. Figure 5 compares the share of STEM doctorates by country for 2018. We found that China and India had the highest share at 62 percent and 56 percent, respectively, while the United States and Russia had about the same share at 43 percent and 42 percent, respectively.

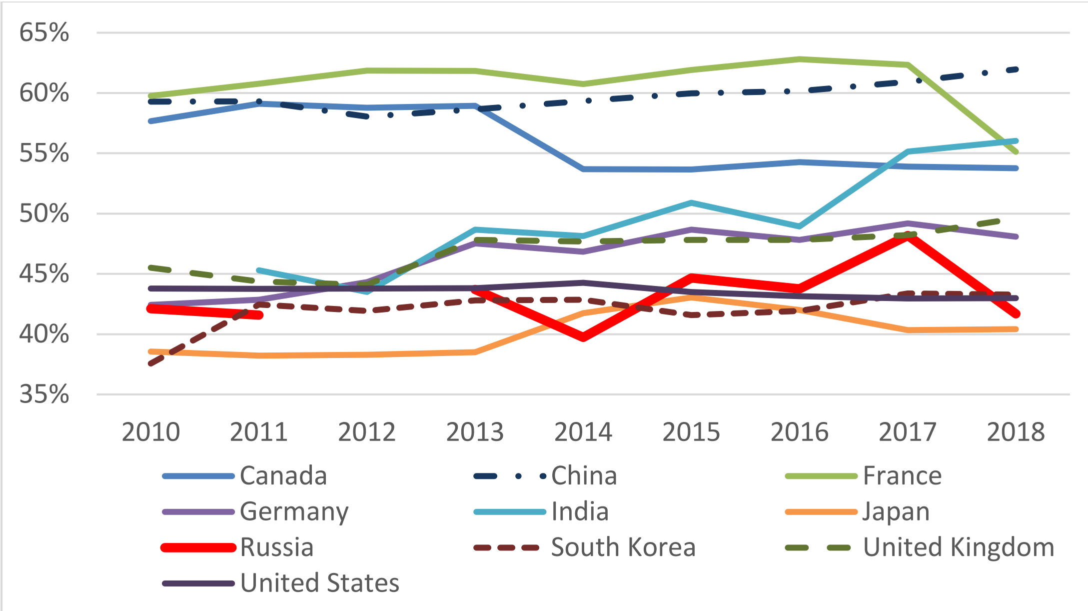


Figure 4. Share of Doctoral Degrees in STEM, 2010–2018

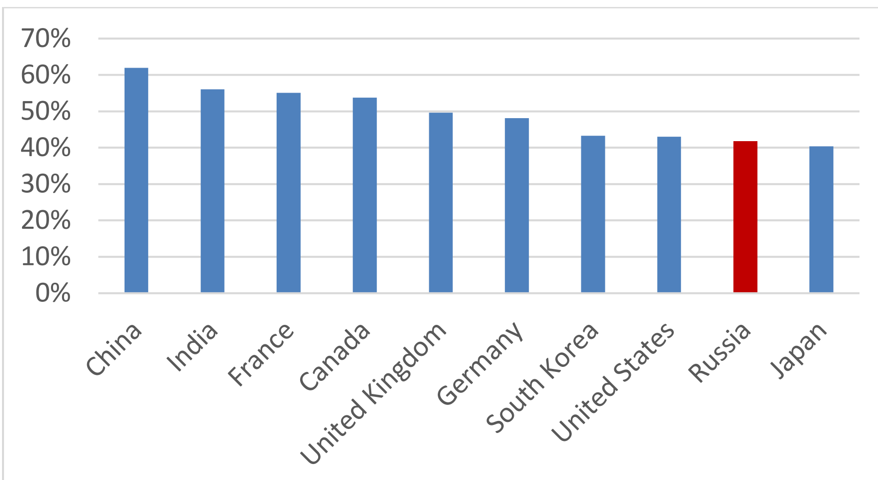


Figure 5. Science and Engineering Doctoral Degrees as a Share of All Doctoral Degrees, 2018

Indicators such as space budgets and degrees are useful for making international comparisons, but they do not predict how prominent a nation will be in space in the future. That said, such benchmarks offer an opportunity to better understand the context under which a spacefaring nation is operating.

In sum, comparison of national expenditures and degree production revealed that while Russia lags behind other top spacefaring nations in investment, space remains a priority based on the relative R&D expenditures. At least through 2018, the percentage of doctoral degrees that were science and engineering degrees in Russia was similar to that in the United States.

3. Russia’s Educational and R&D System

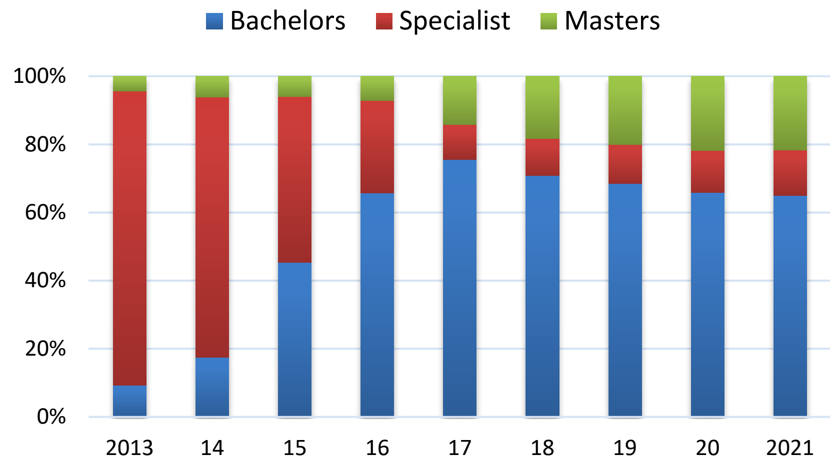
A. Historical Context

The educational and scientific system in Russia was established in the 1930s and is best understood in the context of its societal purpose. Recent analysis of historical policy documents (Smolentseva 2017) revealed that with the exception of sources issued during *perestroika* and the early post-Soviet period, education was described as an instrument to serve the economic and political interests of the state, not the personal growth and intellectual development of students.

During the Soviet period, the government used several levers to tightly control the supply and demand for the educated workforce. Centralized planning of education mandated that each university graduate a specified number of students in necessary specializations. State-owned enterprises were ordered to hire a certain number of these graduates, who were given mandatory assignments to fill the specified positions (Froumin et al. 2015). In the isolated, inward-looking Soviet system, this strategy worked reasonably well, especially in the fields of engineering, healthcare, and science (expert interview February 2022; Froumin et al. 2015).

The emergence of a new economy after the fall of the Soviet Union upended these aspects of the Russian educational system. Academic institutions were allowed more flexibility to define their mission and educational strategy. Students no longer were assigned mandatory jobs, but had to find employment themselves. Private universities were set up, tuition introduced; the opening of borders meant that Russian students could attend universities abroad, introducing competition into the system (Froumin et al. 2015).

Important changes were also occurring in university education in the European Union (EU). In 1999, 29 countries signed the Bologna Declaration, an agreement to harmonize the systems of higher education in the EU (Huisman 2019). Russia joined this effort in 2003 despite strong opposition from Russian faculty, students, and parents (Platonova et al. 2018). To adopt the Bologna framework with minimum disruption, Russia maintained the existing specialist degree (5–6 years depending on the field), while introducing bachelor’s and master’s degrees (4 and 2 years, respectively). Nearly 20 years later, the transition remains incomplete and many universities offer both tracks, although the number of specialist degrees granted has declined sharply (Figure 6). A single PhD degree to replace the traditional Russian two-tier system of candidate of science/doctor of science degrees had not been adopted outside of very few Western-oriented institutions in Russia.



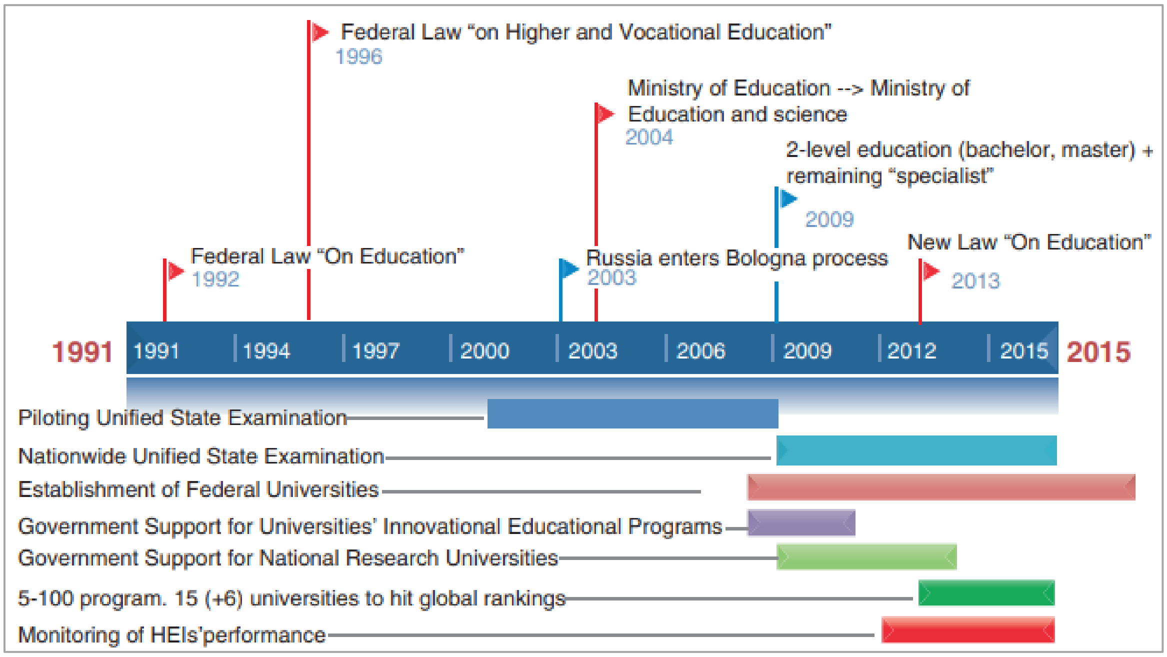
Source: Russian Ministry of Education. Translated from Russian.

Figure 6. Percent of Graduates with Bachelor's, Specialist, or Master's Degrees from Russian Institutions, 2013–2021

Closer integration with the European Union exposed weaknesses in the Russian educational and scientific system. Russian universities lagged behind their peers in the EU on many measures of success, such as publication output and university rankings. The Russian government responded by making global competitiveness in higher education a national goal and increasing expenditures on science and education. Between 2000 and 2013, public expenditures on education doubled from 0.5 percent of GDP to 1 percent (Abdrakhmanova et al. 2014). The increase was especially significant for higher and postgraduate education, with a nearly three-fold increase, from 0.3 percent of GDP to 0.8 percent.

From 2003 to 2005 many important changes in Russian science and education occurred. Figure 7 presents a timeline of major education milestones. First, 29 institutions were competitively selected for a special status of "national research university" and given substantial resources to increase their capacity and international standing (Froumin et al. 2015). Ten regional institutions were given the status of "federal universities" and an infusion of funds, so that they could develop talent outside the intellectual centers of Moscow and Saint Petersburg. To promote economic development, universities were allowed to partner with the private sector, and efforts were made to attract foreign and expatriate scientists to Russian universities (Gershman et al. 2018). The national state examination replaced the patchwork system of university-specific entry exams (Platonova et al. 2018).

Despite these efforts, Russian universities continued to lag in global rankings. In 2012, the Russian government launched a project to advance at least 5 Russian universities into the top 100 slots by 2020 (the 5–100 Initiative). Twenty-one universities were competitively selected and provided with funding to improve their positions in international rankings (Agasisti et al. 2019). These 29 universities, along with the national and federal research universities (groups that overlap) have been given special, high-prestige status in Russia, and receive funding support directly from the government. Consequently, they attract the best students and faculty and produce significantly more publications than other Russian universities (Platonova et al. 2018).



Source: Platonova 2018

Figure 7. Key Developments in the Russian Educational System after the Fall of the Soviet Union

In addition to its efforts to boost the status of Russian universities, the government committed $3 billion to create Skolkovo, an innovation center located at the outskirts of Moscow. Skolkovo was supposed to become Russia’s Silicon Valley (Martin 2020). The crown jewel of this effort was the establishment in 2010 of the Skolkovo Institute of Science and Technology (Skoltech 2021) in partnership with the Massachusetts Institute of Technology (MIT). The stated mission of Skoltech was to become an “international university of a new type in Russia, fostering research in advanced areas of crucial importance for Russia and the world” (Skoltech n.d.). Skoltech follows the Bologna educational process; all instruction is in English. Within 10 years, Skoltech acquired impressive new facilities (Figure 8), recruited dozens of faculty members trained in the West and vetted by MIT, and launched several graduate programs accredited in the EU (Skoltech n.d.). In 2020, 23 of its researchers were included among the top 2 percent of authors by citation impact (Skoltech 2020).

The scientific portfolio of Skoltech is organized around several “target domains” deemed strategically important. Initially, these domains included space technology, but it was no longer listed as a priority in the most recent strategic plan, for 2021–2025. In that plan, the focus areas included artificial intelligence technology, molecular and cellular biology, digital engineering, energy science and technology, photonic science and engineering, and advanced studies that include theoretical mathematics and physics. Despite some concerns from the U.S. intelligence community, the MIT-Skoltech partnership was extended in 2019 for another 5 years (Martin 2020).

Source: Skoltech.ru, n.d.

Figure 8. Skoltech Campus

The Russian government made other efforts over the past 5 years to improve Russian science. The Russian Science Foundation, established in 2014, was the first Russian agency to competitively award grants based on peer review. In 2018, a new national research strategy called for additional support for early-career scientists, more funding for research, and the establishment of 900 new laboratories by 2024 (Schiermeier 2020). The Russian government also completed an evaluation of Russian educational institutions based on their scientific performance and promised additional funding to the top 300.

Despite these initiatives, science in Russia remains more poorly funded than in EU countries and the United States and Russian scientists are less productive than their peers in other countries (Schiermeier 2020). Russian authors acknowledge that Russia’s system of higher education is inflexible, offering students few options to experiment with academic subjects and careers (Kondratjeva et al. 2017). The brain drain from Russia has never ceased and the climate for scientists has become more oppressive since the annexation of Crimea in 2014.

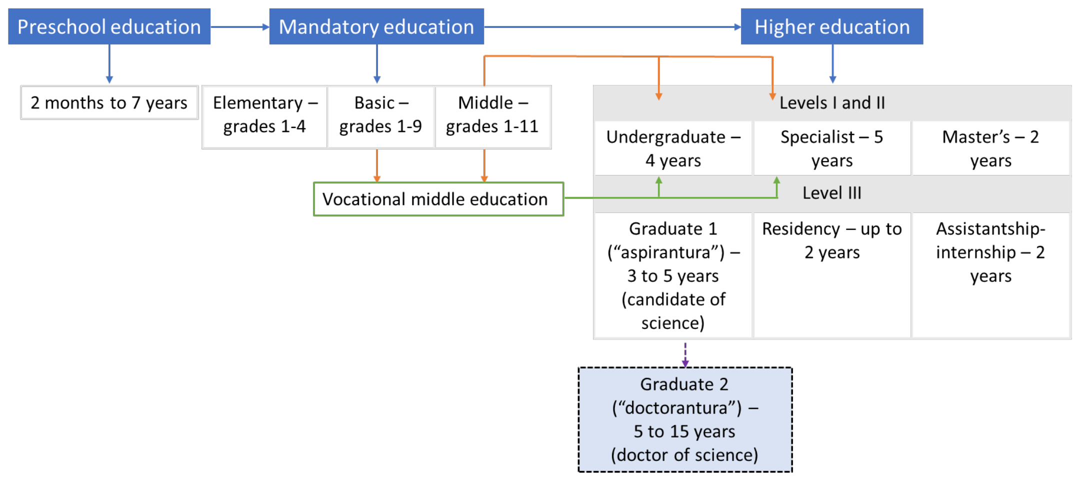
The Russian invasion of Ukraine in February 2022 has impacted the scientific enterprise across the country. The reaction from the international scientific community to the war was swift. Two days after the invasion, MIT severed its relationship with Skoltech. Germany, Russia's top partner in science, put on hold international collaborations with Russia and the European Organization for Nuclear Research (CERN) suspended Russia's observer status (Plackett 2022). Two of the most important international publication databases, Web of Science and Scopus, stopped offering services in Russia (Chawla 2022). In June 2022, the White House of Office of Science and Technology Policy announced that it was winding down "institutional, administrative, funding, and personnel relationships and research collaborations in the fields of science and technology with Russian government-affiliated research institutions and individuals." U.S. agencies and government laboratories also curtailed scientific relationships with Russia (The White House 2022a).

The resulting isolation, combined with the loss of talent to emigration, is expected to significantly undermine Russian science and reverse the gains of the last decade (Plackett 2022; Azvolinsky 2022), although the full impact of the war is difficult to determine at this time. Alexander Nozik, a physicist at the Moscow Institute of Physics and Technology, summed up the situation: "The future of Russian science hinges on whether President Vladimir V. Putin stays in power. It is my belief that it is not possible to do modern science in Russia under Putin's regime" (Chawla 2022).

In conclusion, despite various efforts to modernize the Russian scientific enterprise, many features from the Soviet era remain. Russian science is underfunded and underperforms relative to other countries that Russia views as competitors. As shown below, Russian science benefited from foreign partnerships. The invasion of Ukraine, which has led to isolation from the international scientific community and the flight of talent, is likely to precipitate a decline in Russia's scientific performance.

B. Primary and Secondary Education

Primary education in Russia is similar to the K-12 system in the United States. Called "mandatory education," it begins at age 7 and is divided into three phases: elementary (grades 1–4), basic (grades 5–9), and middle (grades 10–11). In 2004, mandatory education transitioned from 10 to 11 grades, with an extra year added after the elementary stage, where it remains today (Government of Alberta, Canada 2016). The educational pathways in Russia are shown in Figure 9. Students interested in certain professions, such as preschool teacher or qualified worker, can attend vocational schools after 9th grade as an alternative to general high school or after completing high school.



Source: Gosuslugi.ru. Translated from Russian and adapted.

Figure 9. Education Pathways in Russia

In the Soviet system, most children received a general education, with no emphasis on a specific subject. An alternative to this general education was *profil'naya shkola* or specialized schools that offer in-depth study in a particular subject, such as mathematics, physics, history, music, or foreign languages. These specialized schools represented a small minority of secondary educational establishments, limited primarily to Moscow and Saint Petersburg.

Several of these specialized schools are famous in Russia (and in the academic circles abroad) for their excellent preparation and as stepping stones to top universities. Students enter these schools from middle school; admission is highly competitive. For example, the legendary Kolmogorov Boarding School affiliated with Moscow State University is a high school that accepts students who plan to study physics, mathematics, chemistry, and biology (Lugovskaya 2019). To be admitted, students must pass two rounds of examinations, the first in their home town and the second at the conclusion of a 2-week intensive summer school on site at the town of Kolmogorov (Lugovskaya 2019). Sixty percent of Kolmogorov graduates go on to Moscow State University and the rest to other top colleges. Another prestigious secondary school is Bauman Engineering Lyceum #1580, which specializes in engineering, mathematics and physics, economics and social science, and chemistry and biology. Like Kolmogorov, it is highly competitive. Most graduates of the school enroll at Bauman Moscow State Technical University. Other well-regarded specialized schools are feeders to the Higher School of Economics (which according to an expert interviewed has surpassed Moscow State University in some fields) and National Research Nuclear University.

In the Soviet Union, undergraduate training lasted 5 to 6 years and led to a degree of "specialist." At most universities the specialist degree continues to be offered along with bachelor's and master's degrees, but the number of students receiving a specialist degree has dropped drastically (Figure 6). A specialist degree can be earned as an extension to a bachelor's degree or directly after high school. Both specialist and bachelor's degrees qualify students to enter a master's program. Under the Soviet system, undergraduate students committed to a narrow specialty when entering college, with few choices in courses or options to change direction. Engagement in the Bologna system was intended to broaden student preparation, but an examination of curricula at several universities suggested that in most cases the Soviet philosophy of highly specialized education has endured.

Students with a specialist or master's degree can continue their education at the graduate level. Only a very small number of universities—such as Skoltech—have adopted a PhD degree. Far more common is a two-tier qualification system of candidate and doctor of science; both ranks mark a scientific rather than educational achievement. A candidate of science degree, *aspirantura*, is generally accepted as the equivalent of a U.S. PhD. The degree, which takes 4 to 5 years to earn, requires completing a research project, passing a qualifying examination, and defending a dissertation. The number of candidate degree slots is limited; applicants must earn high scores on several exams to be considered for admission.

The doctor of science is the highest professional qualification. It can be earned in one of 25 academic specialties, including the biological sciences, the arts, philosophy, and the physical sciences. In addition to having been granted a candidate degree, eligible researchers must show a significant scholarly contribution to their field (publishing 10 to 20 scientific papers) and hold a teaching or research position at a recognized institution. Earning a doctorate degree takes at least 10 years of full-time research; only a quarter of scientists achieve this qualification. Traditionally, scholarly work toward the doctor of science is performed at research institutes, not universities, and until recently the degree was granted by a special commission rather than an educational or research organization. Since 2016, 29 universities have been authorized to award the title of doctor of science (Documents of Russian Government 2017). There is no equivalent to the doctor of science qualification in the United States. In light of the amount of time it takes to earn the degree and the expected intellectual contribution, the degree is more similar to an academic title of an associate or full professor than a PhD. Table 1 summarizes the steps in higher education and professional training in Russia, listing the requirements to enter, degrees and diplomas attained at completion, the nature of the education, examinations, and the next professional steps.

Table 1. Higher Education and Training in Russia

	Level I	Level II		Level III		
	Undergraduate	**Specialist**	**Master's**	**Graduate**	**Residency**	**Assistantship-internship**
Prerequisite education	Mandatory level	Mandatory level	Bachelor's or specialist	Specialist or Master's	Medical or pharmacy	Specialist or Master's in culture studies
Duration in years	4	5–6 after mandatory education or 1 after undergraduate	2	3–5	Up to 3	2
Diploma	Yes	Yes	Yes		Yes	Yes
Degree or certification	Bachelor's	Specialist	Master's	Candidate of science	Specialty physician	Specialist with highest qualification
Nature of preparation	General	Specialized	Deeply theoretical, orientated toward further scientific training	Mentored scientific work	Deep clinical studies; acquisition of practical medical skills	Mentored work
Examination, accreditation	State exams, defense of undergraduate project	State exams, defense of project	State exams, defense of master's thesis	Defense of candidate of science dissertation	Specialist accreditation	Creative or performative work (e.g., play, film)
Next step		Master's or graduate school	Graduate school	Defense of doctor of science dissertation	Graduate school	Graduate school

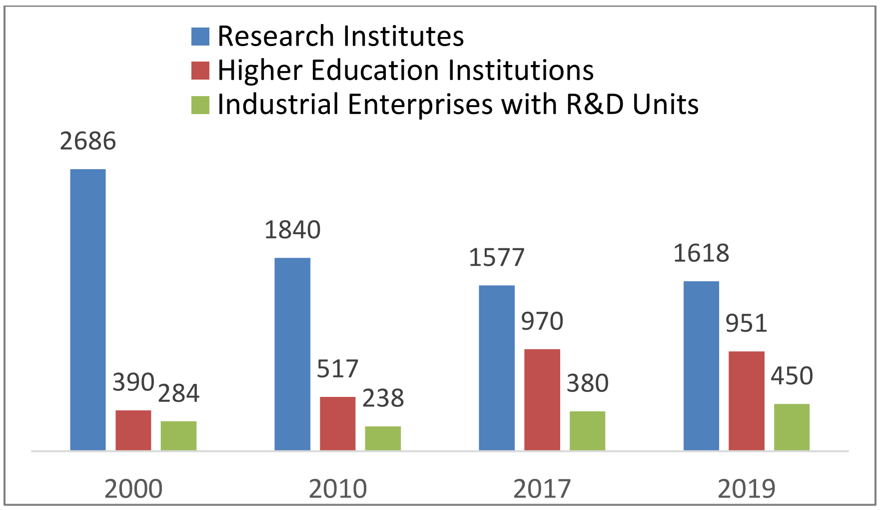
Source: Gosuslugi.ru. Translated from Russian.

In sum, the educational path in Russia is characterized by early specialization and limited options for changing direction once admitted to college.

C. Educational and Research Institutions

After the dissolution of the Soviet Union, the system of higher education in Russia became internally more competitive. In 2012, the Ministry of Education assessed all institutions of higher education on a set of 50 performance measures. The review led to the closure or merger of 21 universities and 156 branches (Froumin et al. 2015). One expert interviewed for this study believes that the number of institutions still significantly exceeds demand for higher education based on Russia's current population.

In the context of this more competitive environment, some higher education establishments changed their titles from "institute" to the more prestigious "university" or "academy." These changes disrupted the naming conventions established under the Soviet system, in which institutes were highly specialized establishments while universities offered broad education. Regardless of their exact titles, academic institutions in Russia can be divided into three categories based on mission, disciplinary breadth, and nature of the education. These are: higher education institutions, industrial enterprises with R&D units, and research institutes. The total number of academic and semi-academic organizations between 2010 and 2019 is shown in Figure 10. This classification is meant to help the reader understand the academic landscape in Russia, and is not a systematic taxonomy of institutions.



Source: Organisation for Economic Co-operation and Development

Figure 10. Number of Russian Academic and Semi-Academic Institutions, 2010–2019

1. Traditional Universities

Universities are large educational institutions that grant undergraduate and graduate degrees in all major disciplines. For example, Moscow State University includes departments of law, journalism, physics, biology, history, economics, political science, and most other fields in humanities, natural sciences, and social sciences. In the Soviet Union, only larger cities had universities, but as of 2005 27 percent of all educational institutions had adopted this title (Government of Alberta, Canada 2016). In many cases, the new names for these establishments are at odds with the historical definitions: for example, many formerly pedagogical, agricultural, and medical institutes are now called "universities" despite their narrow focus.

Universities are organized into *facultets,* which are further divided into more specialized units called *kafedras*. At very large universities, like Moscow State University, a *facultet* is roughly equivalent to a school and a *kafedra* to a department. For example, the *facultet* of biology at Moscow State University houses a dozen *kafedras*, including genetics, immunology, bioengineering, and virology. At smaller educational institutions a *facultet* is more akin to a university department in the United States.

The Russian educational system emphasizes narrow professional preparation and early acquisition of practical skills. To further this goal, in their final years of study undergraduate students are connected to prospective employers (both commercial and academic) through mandatory internships and practicums. In 2014, a new type of arrangement, called *base kafedra* was introduced, whereby institutions of higher education formally partner with specific industry or research organizations (Postupi 2022). Partner contributions to these programs extend beyond offering employment opportunities to include supervision of research projects and even revisions to the curriculum to achieve the right balance of theory and practice. These measures are meant to ensure that the graduates, most of whom will eventually join the partner organization as employees, have the right skills and knowledge for the particular employer. The selection of students to join *base kafedra* generally takes place during their second or third year or in some cases upon being accepted to the university. Admittance to *base kafedras* is very competitive (in some cases only one of 20 applicants is selected), and requires additional examinations and higher examination scores than enrollment in the same university. Based on the literature and review of university websites, only a small number of top universities have these programs.

2. Specialized Institutes and Academies

Most institutes and academies grant the same degrees as universities, although academies are more likely to offer graduate programs than institutes. They are more narrowly focused on one scholarly area or several related areas and training is more applied. Before the collapse of the Soviet Union, most educational establishments were called institutes, with each name announcing their specialization, such as the Moscow Aviation Institute or the First Moscow Medical Institute. Educational institutions calling themselves “academies” are different from but easily confused with the Russian Academy of Sciences (RAS) described below.

Military academies are professional educational establishments for experienced commissioned officers; they require a bachelor’s degree to enter. Graduating officers receive a master’s degree and can continue their education toward a candidate of science (PhD-equivalent) diploma.

3. Research Institutes

In contrast to the United States where research is performed primarily at universities, Russia has a long-standing tradition of separating research from teaching (Kuzminov et al. 2018). Most research takes place at RAS, a network of many scientific organizations that include research institutes, observatories, libraries, and other entities. In addition to engaging in scientific activities, research institutes serve as sites where scholars earn candidate and doctorate degrees, while undergraduate education remains the purview of universities. Staff at research institutes serve as professors at local universities (Froumin et al. 2015), and university students attend seminars and work on projects at research institutes (expert interview February 2022). More recently, universities have begun to play a larger role in research. In addition, new unaffiliated scientific institutes had been established. According to one estimate, approximately half of the 1,000 research organizations in Russia are currently independent of RAS (Edunews.ru n.d.).

RAS deserves special mention because of its historic importance to Russian science, its large size, and its recent marginalization that may have a direct impact on the space sector. Established by Peter the Great in 1724, it is organized by discipline into 13 branches, which employ approximately 125,000 people. RAS also grants honorary membership to domestic and international scholars (approximately 1,800 and 500 members in 2021, respectively; Wikipedia 2022b). In this respect it is similar to the U.S. National Academy of Sciences.

RAS includes several institutes focused on space exploration. The most important of these is the Institute for Space Research (ISR) established in 1965. As of 2021, it employed 954 staff who worked on 225 projects (Institute for Space Research n.d.). Other institutes involved in the space sector include the Lebedev Physics Institute, which has an astrophysics branch (Lebedev Institute of Physics n.d.), the Institute for Astronomy, the Institute for Applied Astronomy, and the Pulkovo Observatory (Wikipedia 2022c).

In 2013, with no warning or consultation with experts, the Russian Government implemented an "academy reform" that dissolved RAS and replaced it with a new entity called the Federal Agency for Scientific Organizations (FASO), which took control of RAS's buildings and other property. The official goal of this reform was to enable scientists to fully devote themselves to research activities and not worry about problems such as building maintenance. However, an expert interviewed for this study believed that the shake-up had been caused by resistance from RAS to support industrialization and weapons development programs (expert interview February 2022).

The proposed changes provoked an outcry among the Academy members, some of whom called the reform "criminal" and pledged to not join the new organization. While the language of the law was softened by the government in response to this reaction, the changes took place as planned. According to the expert interviewed for the study and an opinion published in the *New York Times* (Chawla 2022), since Putin's restructuring the RAS has become primarily an honorary body, with no power to set or implement a research agenda. However, a number of commentators argued that some changes to RAS were necessary. An article in the journal *Nature* (2013) noted that only a small number of RAS institutes conducted internationally competitive research (Russian Roulette 2013).

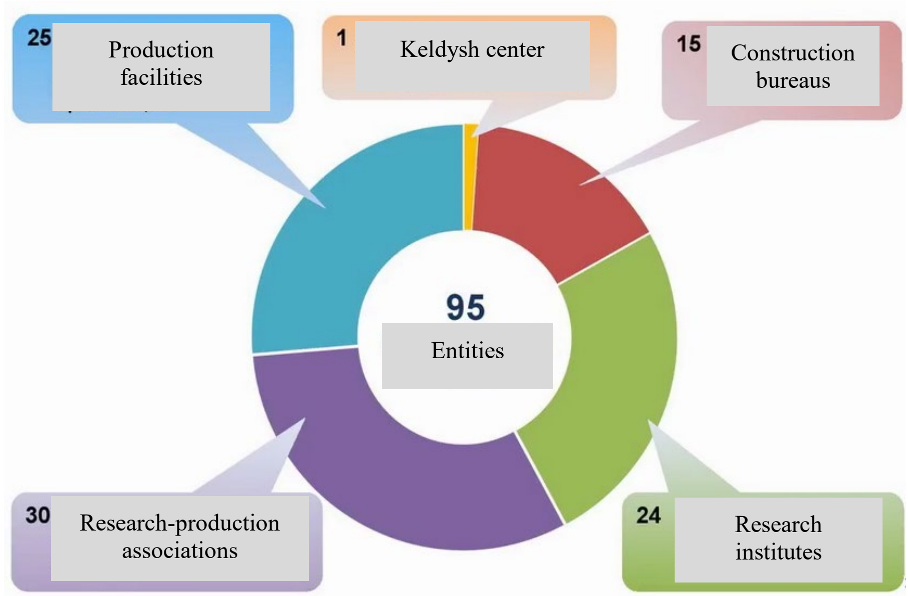
D. Roscosmos

A review of the literature and case studies of educational institutions shows that Roscosmos is the single largest employer of talent in the space sector. Roscosmos is a state-owned corporation that resulted from a merger in 2015 of the Russian Federal Space Agency (formed in 1992) and the United Rocket Space Corporation, following a series of embarrassing rocket failures and revelations of bureaucratic inefficiencies (Howell 2018). In 2016, the Russian government issued Decree No. 824, transferring federal ownership of stock in 46 companies to the Roscosmos State Corporation. It is worth noting that while many companies under Roscosmos's umbrella are private commercial entities, they behave like state-run entities in terms of the centralized control of decision making and resource distribution. Since its establishment, Roscosmos has managed all aspects of Russia's rocket and space industry, including policy making, strategic planning, business, and economic activities (Pravo 2015). According to one source, Roscosmos's budget for civilian projects for 2021 was $1.9 billion (RBC.ru 2020).

Roscosmos is organized around eight areas: (1) human space flight, (2) launch systems, (3) unmanned spacecraft, (4) rocket propulsion, (5) military missiles, (6) space avionics, (7) special military space systems, and (8) flight control systems (Aliberti et al. 2019). It is a sprawling corporation composed of at least 95 entities, which span the entire space industry value chain—from R&D to commercialized products, as shown in Figure 11. Roscosmos appears to be in flux, with many leadership changes taking place over the past few years. It has also tried to boost productivity, including an anticipated reduction of 1,500 staff at Khrunichev State Space Research and Production Center, which is viewed as lagging behind its performance targets (Hrlider.ru 2021). The changes in leadership and reorganizations are designed to address structural challenges, such as streamlining industrial processes, eliminating excess manufacturing capacity, misuse of funds, and improving innovation, among other challenges. However, using open sources it will be increasingly difficult to determine to what extent these measures have been effective due to the September 2021 order issued by the Federal Security Service of the Russian Federation (FSB) that prohibited sharing information about Roscosmos with unauthorized individuals. Many of the corporation websites were blocked after the Ukraine invasion.

The corporation employed 170,500 people in 2020 (Wikipedia 2022d). Roscosmos salaries for engineers that year were 75,000 to 80,000 rubles ($1,018 to $1,086) per month, plus bonuses that could represent up to 120 percent of the salary (Hrlider.ru 2021).[1] For comparison, the median salary in Russia in 2020 was 34,000 rubles ($462) per month (Tass 2021).

[1] Calculated using the average annual ruble/dollar exchange rate in 2021 of 73.7 rubles to the dollar (IMF n.d.).



Source: PowerPoint presentation, n.d. Translated from Russian.

Figure 11. Organization of Roscosmos

Several of Roscosmos's subsidiaries and research institutes repeatedly emerged from the literature and case studies as employers of university graduates. These entities include Russian Space Systems (5,600 employees), Lavochkin Scientific and Production Association (5,100), Rocket and Space Corporation Energia (6,800), Energonash (6,000), Khrunichev State Space Research and Production Center (20,000), Information Satellite Systems (8,000), Keldysh Research Center (1,000), and the Central Research Institute of Mechanical Engineering (6,500; Hrlider.ru 2021). Keldysh and Lavochkin are also accredited to grant candidate of science degrees in applied physics and space engineering.

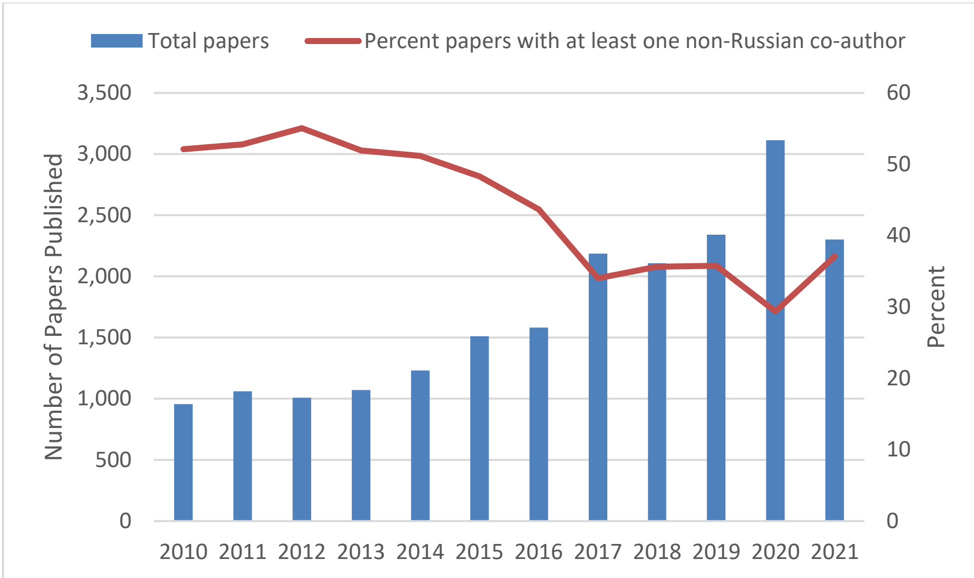
In sum, Russia has largely maintained its historical division between universities that are primarily devoted to education and research institutes within the Academy of Sciences that focus on research. Universities and research institutes are closely connected, however, with faculty and students moving between these organizations. In the space sector, several of Roscosmos's units focus on space R&D and are major employers for university graduates.

4. Research and Development Environment and Productivity in Russia

A. Publication Productivity and Impact

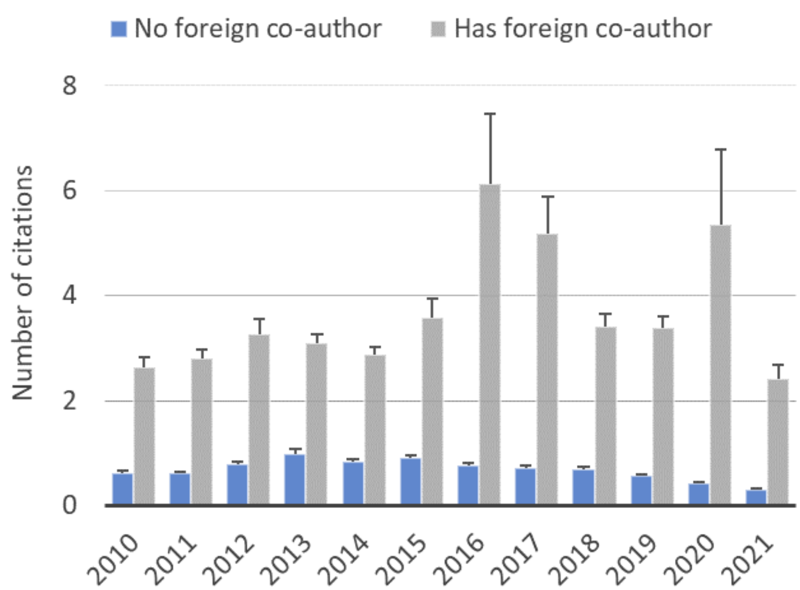
STPI analyzed a dataset of publications in space fields for the years 2005–2021 available from Web of Science. Of 454,723 papers in this dataset, 23,097 included at least 1 author affiliated with a Russian institution. Details on how STPI determined the publication set can be found in Appendix A. Publication productivity and co-authorships with foreign scientists are shown in Figure 12. The total number of publications per year more than tripled over the last decade, from 956 in 2010 to 3,114 in 2020. The decline in the number of publications in 2021 is consistent with the worldwide loss of research productivity that has been attributed to the COVID-19 pandemic.

STPI also examined the proportion of publications with foreign co-authors, also described as non-Russian co-authors. In the entire dataset spanning the years of 2005 to 2021, 42 percent of papers had a foreign co-author. Analysis of publications by year revealed a decline in the papers that had a foreign co-authorship from 52 percent in 2010 to 37 percent in 2021 (Figure 12). STPI also observed that the number of co-authorships in 2021 was higher than the previous year, 37 percent compared to 29 percent, possibly due to an increase in remote communication during the pandemic. Investigation of citation patterns showed that papers with a foreign co-author had five times more citations than the papers that were written only by Russian authors: 3 per paper compared to 0.6, on average (Figure 13). This difference is highly statistically significant ($p<0.001$).



Source: Web of Science Space Publications; See Appendix A

Figure 12. Number of Russian Papers with at Least One Non-Russian Co-Author in Space Journals, 2010–2021



Source: Web of Science Space Publications; See Appendix A

Figure 13. Citation Impact of Papers in Space Journals with and without Foreign Co-Authorship, 2010–2021

Based on the publication tags, of the 23,097 papers with Russian authors in the dataset, 59 percent were in the fields of astronomy and astrophysics. STPI found that for papers that were not in these fields (9,361 in total), only 16 percent had a foreign co-author versus 42 percent for all 23,097 papers in the dataset. This finding is consistent with prior results showing that astronomy and astrophysics are highly collaborative fields (Smith 2016).

Authors affiliated with U.S. institutions were the most frequent collaborators of Russian scientists at 15 percent, followed by Germany at 13 percent, France at 8 percent, and the United Kingdom and Italy at 7 percent each. These results are consistent with a UNESCO study that examined co-authorships of scientists from Russia and other countries between 2017 and 2019 (Hudson 2022) and with an analysis of co-authorship patterns in 82 top science journals conducted annually by *Nature* (Nature Index 2021–2022). For the subset of 9,361 papers that excluded astronomy and astrophysics, the top 3 collaborating countries were the same as for the whole dataset, with U.S.-affiliated scientists co-authoring 4 percent of papers, followed by scientists from Germany and France at 2 percent each.

Table 2 shows the top 10 institutions in Russia by number of papers based on the affiliations in the publication dataset. Moscow State University topped the list with 3,466 papers or 15 percent of the total; no other institution contributed more than 5 percent of the total number of papers. The list excludes nearly 10,000 papers (43 percent of the total) with affiliations listed as RAS without identifying the specific institute. This number is likely the sum of several organizations within the RAS network that are focused on space and is therefore not comparable to the productivity of the individual institutions. For the subset of papers excluding astronomy and astrophysics, Moscow State University was again the most productive (501 papers or 5 percent), followed by Tomsk Polytech University (384 or 4 percent).

Table 2. Most Productive Russian Institutions Publishing in Space Journals

Institution	Number of Papers	Percentage of Total Papers
Moscow State University	3,466	15
St. Petersburg State University	1,256	5
Kazan Federal University	801	3
Institute of Space Research (RAS)	581	3
Ioffe Physical-Technical Institute (RAS)	513	2
Lebedev Physical Institute (RAS)	492	2
Pulkovo Observatory (RAS)	449	2
Moscow Engineering Physics Institute	411	2
Tomsk Polytechnic University	403	2
Ural Federal University	397	2
Moscow Institute of Physics and Technology	391	2
Novosibirsk State University	345	1

Institution	Number of Papers	Percentage of Total Papers
Ural Federal University	328	1
St. Petersburg Polytechnical University	302	1
Institute of Terrestrial Magnetism, Ionosphere, and Radiowave Propagation (RAS)	295	1

Source: Publication dataset

B. Scientific Integrity

In October 2019 the Commission Against Falsification of Scientific Research appointed by RAS published a report of its investigation into potentially fraudulent publication practices (Kpfran.ru 2020). The report stated that the Commission asked 541 Russian journals to retract 2,528 papers that contained plagiarism, questionable authorship, or duplicate publications; at least 869 papers from 263 journals were subsequently retracted. Remarkably, the RAS president subsequently accused its own Commission of violating the publication clearance process and challenged its findings. It was announced that the composition and responsibilities of the Commission will be changed and different data sources used in the future to investigate fraud (Kpfran.ru. 2018). The RAS probe was not the only source that alleged publication fraud. *Antiplagiat* (plagiarism detection service) identified more than 70,000 articles that were published multiple times and the website 123mi.ru claimed that more than 10,000 researchers bought slots on manuscripts that had been accepted for publication (Chawla 2020).

C. Academic Freedom

Open sources appear to be reporting that harassment and intimidation of scientists in Russia has increased over the past few years. In October 2019, heavily armed police raided the Lebedev Physics Institute at RAS and charged its director with the illegal transfer of goods to Germany (the offending item was glass windows made by one of the Institute’s spin-off companies). The charges were eventually dropped, but the investigation continued at the time of writing. In another case, one RAS-affiliated scientist told Russian President Putin that her salary was only 25,000 rubles ($339) per month. She was later visited by investigators who pressed her to reveal who had encouraged her to complain (RT 2021).

Russian interactions with the international community have also become strained. A new law was passed in March 2021 that requires educational institutions to seek approval from state authorities for various activities involving foreigners, including participation in scientific events not organized by the government, foreign travel, and the exchange of samples with foreign collaborators (RT 2021). A researcher in the United States on leave from a Russian university approached for an interview by STPI said that all foreign travel, whether professional or personal, had to be reported. This individual felt it was unsafe to speak with us.

In September 2021, the FSB issued an order defining the types of information related to the space sector that did not rise to the level of a state secret but nevertheless could be used against the security of the Russian Federation if obtained by foreign nationals or organizations (Nazarbekian 2021; FSB Order 2021). The 60-item list included "information on the use of cryptography, quantum technology, and artificial intelligence to develop new weapons or equipment with the exception of what is available from open sources," and much of the information related to Roscosmos. Persons violating the order risked being labeled "foreign agents." Based on newspaper reports, the climate in Russia has become increasingly oppressive since the invasion of Ukraine. A recent story in the *New York Times* described cruel and inexplicable arrests of scientists, including a dying physicist snatched from his hospital bed (Troianovski 2022).

In sum, a dozen Russian universities and RAS institutes publish most of peer-reviewed English-language publications in space-related journals indexed by *Web of Science*. Forty-two percent of publications included a foreign co-author, with the United States being the most common collaborating country. Most collaborations were on papers in the fields of astronomy and astrophysics. The quality of publications measured by the number of citations is significantly higher when they include a foreign co-author. Russia has encountered many plagiarism scandals suggesting that the ethical standards in its academy are low. International isolation and intimidation of scientists are likely to further damage Russian science.

5. Preparation of Talent for the Space Sector

A. Educational Paths

A career in the space sector can begin as early as high school through participation in summer programs, *olympiads* (academic youth competitions very popular in Russia), and lectures. These activities are sponsored by both universities that prepare students for the space industry and by Roscosmos. For example, Bauman Moscow Technical University (one of the key educational institutions in the sector) has a Youth Space Center (established in 1989), which hosts numerous events and programs to interest students in space careers. Some universities recruit talented high school students—often *olympiad* winners or finalists—and provide scholarships for their university education. Various specialized schools, such as Kolmogorov Boarding School or Moscow Secondary School #15, focused on mathematics and physics, are also direct feeders to top universities.

Roscosmos and several institutes at RAS are the main employers of university graduates in the space sector. These organizations maintain close ties with universities and serve as sites for hands-on experiences that are part of the typical curriculum. These organizations ultimately employ many graduates once they complete their education. According to one source, it is difficult to obtain a position at Roscosmos “off the street.” The path to a job with this largest employer in the space sector lies through high school recruitment programs, college practicums, and in a few cases by demonstrating exceptional skills by winning a prestigious competition (Tass 2021; FEFU News 2021). Similarly, students interested in an academic career enter a research institute by working there as undergraduates and continue their studies to become a candidate of science after graduation. According to one expert interviewed, an academic path requires at a minimum a candidate degree, while industry organizations generally employ engineers with an undergraduate (either bachelor’s or specialist) or master’s degree. Figure 14 shows the path from education to employment, beginning in high school.

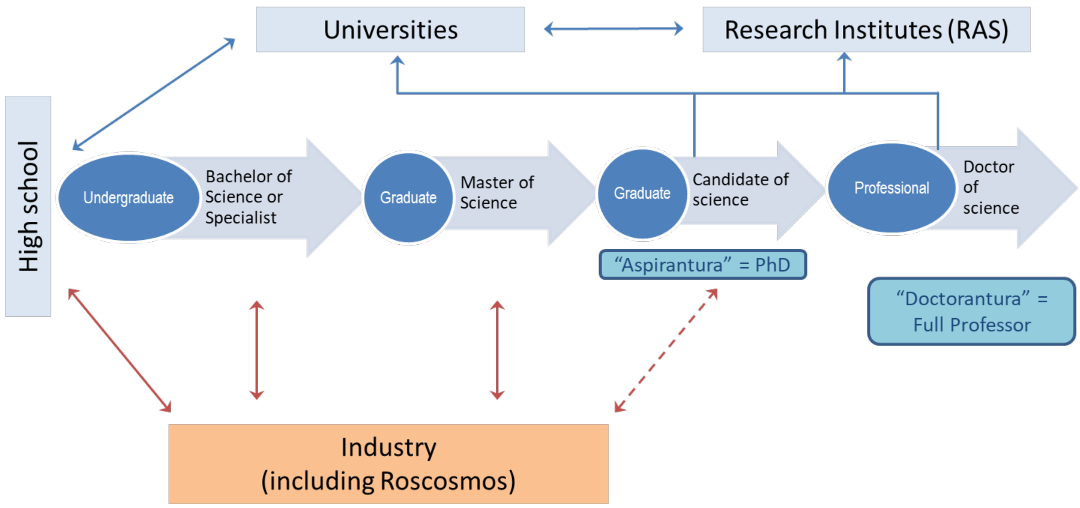


Figure 14. Education to Employment Path in the Russian Space Sector

B. Case Studies of Key Institutions in the Space Sector

Based on a literature search, bibliometric analysis, and interviews with two key informants, STPI identified 74 organizations involved in developing and employing space talent. Of these, 33 were universities, 14 research institutes, 14 industry organizations, and 4 military academies. Fifteen organizations were selected for further study based a combination of volume of publications in Russian or English language space journals, expert opinion about the importance of these organizations, and the nature of the organizations. The last criterion was used to ensure that case studies were not limited to universities.

Table 3 includes the list of 15 entities (3 industry organizations or Roscosmos research subsidiaries, 7 universities, and 5 research institutes) and how they fit the various criteria. STPI notes that Concern Almaz-Antey and Keldysh Research Center were selected in place of three Roscosmos subsidiaries that had been initially chosen for a case study (Corporation Russian Space Systems, Energomash Scientific Research and Production Corporation, and Rocket and Space Corporation Energia), as websites of these organizations were not accessible at the time of the research.

Table 3. Case Study Institutions

	Institution	Literature Review	Expert Opinion	Top 50 in WoS (En)	Top 50 in WoS (Ru)
Industry and Roscosmos R&D subsidiaries					
1	Concern Almaz-Antey*				
2	Lavochkin Research and Production Association (Lavochkin)	X			
3	Keldysh Research Center (Keldysh)*	X			
Universities					
4	Bauman Moscow State Technical University (Bauman)	X	X	X	X
5	Kazan Federal University (Kazan)	X	X	X	X
6	Moscow Aviation Institute (MAI)	X	X		
7	Moscow Institute of Physics and Technology (MIPT)	X	X	X	X
8	Moscow State University (MSU)	X	X	X	X
9	National Research Nuclear University (Nuclear University)	X		X	X
10	Samara University (Samara)	X	X	X	
Research Institutes at the Russian Academy of Sciences					
11	Central Astronomical Observatory Pulkovo (Pulkovo Observatory)	X			
12	Institute of Biomedical Problems	X	X		X
13	Lebedev Institute of Physics	X		X	
14	Institute of Solar-Terrestrial Physics				
15	Institute of Space Research	X	X	X	X

Note: WoS search for 2017–2022, April 20, 2022 (English: space, Russian: косми). Filter country Russia.
*Alternatives to Roscosmos subsidiaries with inaccessible websites.

1. Programs

The website of each organization in the sample was reviewed to identify degree granting programs, number of students, and domestic partnerships. The search focused on workforce-related information for each organization, not the nature or scope of their R&D activities. For universities, only the departments that were closely related to the space sector were examined.

Table 4 shows space-adjacent degrees with the number of slots. The data revealed that all the universities offered undergraduate and graduate degrees through candidate of science, with the specialist degree being more prevalent than the bachelor's degree in these fields. Candidate of science degrees can also be earned at all research institutes, including the two Roscosmos subsidiaries, Lavochkin and Keldysh. Almaz-Antey is a manufacturing company that does not grant degrees.

STPI notes that the total number of slots per program was not always available, and in some cases, it was unclear whether these slots were the total for all years of study or per year. At Bauman Moscow State Technical University, Moscow State University, the Moscow Institute of Physics and Technology, and Samara University—which had the most complete data for all programs—the totals for all programs from a bachelor's of science to candidate of science were 923, 154, 313, and 772, respectively (excluding the numbers for candidates of science for Samara, which were not available). In total, these numbers sum to a few thousand graduates per year across all degrees and educational institutions in Russia as reported in the government data, suggesting that the organizations included as case studies are significant suppliers of talent to the space sector.

The review of websites revealed that universities and research institutes offer several degree programs (Table 4) in a range of specializations, including aircraft design, navigation systems, propulsion, nuclear propulsion and space instrumentation, remote sensing, aerodynamics, missile systems, astronomy, astrophysics, and space biology and medicine. No clear pattern emerged between type of degree and the nature of specialization. The duration of training, when stated, was 2 years for a master's of science and 4 to 5 years for a candidate of science degree, which were consistent with other fields (see introduction).

Table 4. Programs and Degrees at the Case Study Institutions

Institution	Number of Programs	Bachelor's of Science	Specialist	Master's of Science	Candidate of Science	Doctor of Science
Almaz-Antey	0					
Lavochkin	1				x	
Keldysh	2				x	x
Bauman	15	x	X	x	x	
Kazan	5		X	x	x	
MAI	12	x	X	x		
MIPT	20	x	X	x	x	
MSU	9		X	x	x	
NRNU	6		X	x	x	
Samara	19	x	X	x	x	
Pulkovo Observatory	4				x	x
Institute of Biomedical Problems	1				x	
Lebedev Institute of Physics	1				x	x

Institution	Number of Programs	Bachelor's of Science	Specialist	Master's of Science	Candidate of Science	Doctor of Science
Institute of Solar-Terrestrial Physics	4			x	x	x
Institute of Space Research	6				x	x

Source: Institution websites

2. Partnerships

One of the key features of student preparation for space in Russia is the acquisition of practical skills. Under the Soviet system, students in their final years of study were required to spend a portion of their time working at an organization in their field. The relationship between educational and employing institutions has grown closer in recent years with the establishment of *base kafedras* and similar educational units.

These educational arrangements were mentioned on the websites of universities included in the case studies. At Bauman, 5 of 11 programs in the space sector (rocket and space technology, aerospace, instrumentation, radio engineering, and opto-electronic instrumentation) are immersion programs, where undergraduate students work at partner organizations throughout the duration of their studies (Table 5). For example, students enrolled in an opto-electronic instrumentation program spend summers after their second and third years and 1 day a week during the term starting in their fourth year at Zenit, a commercial organization that specializes in aerospace photographic equipment, ground observation systems, cameras, and medical precision instruments. Similarly, students at the Department of Rocket and Space Technology work on projects at Corporation Energia and students at the Department of Radio Engineering work at Almaz-Antey—both large industrial corporations. Moscow Institute of Physics and Technology also has strong ties to industry. Its partners include Corporation Energia and several Roscosmos R&D subsidiaries (Keldysh Research Center, Russian Space Systems, and the Central Research Institute of Machine Building). Moscow Aviation Institute partners with Lavochkin.

Table 5. Educational Programs That Include Partnerships with the Space Industry

University	*Kafedra* or program	Partner
Bauman	Rocket and space technology	Rocket and space corporation Energia
Bauman	Instrumentation	Center for Ground-Based Space Infrastructure Facilities Operation
Bauman	Aerospace	Military-Industrial Corporation Mashinostroeniye
Bauman	Opto-electronic instrumentation	Zenit

University	*Kafedra* or program	Partner
Bauman	Radioengineering	Scientific and Production Association Almaz-Antey
MIPT	Aerophysical Mechanics	Energia
MIPT	Traffic control	Energia
MIPT	Propulsion and power plants	Keldysh Research Center
MIPT	Space instrumentation	Russian Space Systems
MIPT	Motion control, space flight dynamics, navigation	Energia
MIPT	Space information systems	Komet
MAI	Design, production, and operation of rockets and space complexes	Lavochkin

Source: University websites

It was clear from the university data that Almaz-Antey, Lavochkin, and Keldysh play an important role in training and employing talent in the space sector. Almaz-Antey Corporation was established in 2002 under the Presidential Decree and the Decree of the Government of the Russian Federation that merged dozens of factories, research and production associations, design bureaus, and research institutes. It underwent further expansion in 2007 and now includes more than 60 enterprises across the country (Concern Almaz-Antey n.d.). The scientific and technical priorities of Almaz-Antey are set by the chief executive officer. It employs 129,000 people, of which 1,068 hold candidate of science degrees and 175 hold doctor of science degrees.

The website of Almaz-Antey mentions relationships with a number of universities, including Bauman, Moscow Institute of Physics and Technology, Moscow Technological University, Baltic State Technical University, Moscow Aviation Institute, Ural Federal University, and Nizhny Novgorod State Technical University. As of December 2016—the latest year for which data were available on the website—296 students were enrolled in graduate programs at partner universities, more than 2,800 students interned at Almaz-Antey that year, and 546 graduates from partner universities were employed by the Corporation. Almaz-Antey also offers free university tuition in exchange for a commitment to take a job at the company. In 2016, nearly 900 applicants received these scholarships at a variety of universities. Lavochkin and Keldysh have similar arrangements with universities.

These types of partnerships also exist between universities and research institutes. For example, the Institute of Space Research at the RAS has a *base kafedra* at Moscow Institute of Physics and Technology called the "physics of space." Students enrolled in this program meet with the RAS scientists and attend their lectures starting in their first year so as to become familiar with the scientific portfolio of these institutes and to find mentors for their undergraduate thesis. The amount of time spent in practicums increases as students advance through their programs. Graduates have an option to continue their education for a master's degree, followed by enrollment in a candidate of science program *aspirantura*. The Institute of Space Research has similar partnership programs with the High School of Economics (in physics of space) and Moscow State University (in remote sensing). Table 6 shows six universities in our sample that are well connected with research institutes, industry organizations, and other universities based on data available on their websites.

Table 6. Ties between Universities, Research Institutes, and Industry Organizations

	Bauman	Samara	MAI	MIPT	Kazan	Moscow State U
Almaz-Antey	✓	✓	✓	✓		
Lavochkin	✓	✓	✓		✓	
Keldysh		✓	✓	✓		
Lebedev Institute of Physics	✓	✓		✓	✓	✓
Institute of Space Research				✓	✓	✓
Bauman		✓		✓	✓	✓
Samara						
MAI						✓
MIPT						✓
Kazan						✓
MSU						

Sources: Institution websites and publication dataset

STPI also examined partnerships between the case study organization and international universities and other institutions based on the publication data. The most common collaborating countries for the 15 institutions were the United States (734 publications), Germany (553), the United Kingdom (361), France (320), and Italy (318)—which was consistent with the partners identified in the entire dataset (see chapter 4). Table 7 shows the top three foreign institutions with at least 50 publications for the 5 case study organizations that had a sufficient number of collaborative publications. STPI notes that NASA emerged as one of the top three collaborators for Moscow State University and the Institute for Space Research. Other case study institutions also co-authored papers with NASA, but they were below the cut-off used in the table (Lebedev n=60, Pulkovo n=51, Institute of Solar-Terrestrial Physics n=12, Moscow Institute of Physics and Technology n=4, Lavochkin n=3, and Institute for Biomedical Problems n=1).

Table 7. Example International Partners of Case Study Institutions

Foreign Institution and Country	Institution	Number of Publications
Max Planck Institute for Astrophysics, Germany	Kazan	78
University of Turku, Finland	Kazan	76
University of Tubingen, Germany	Kazan	68
NASA, U.S.	MSU	181
University of Tokyo, Japan	MSU	152
University of Paris Diderot, France	MSU	132
Max Planck Institute for Radio Astronomy, Germany	Pulkovo Observatory	71
University of Turku, Finland	Pulkovo Observatory	52
Caltech, U.S.	Pulkovo Observatory	51
Max Planck Institute for Radio Astronomy, Germany	Lebedev Institute of Physics	152
Natal Radio Astronomy Observatory, U.S. (NSF)	Lebedev Institute of Physics	61
Purdue University, U.S.	Lebedev Institute of Physics	61
Max Planck Institute for Astrophysics, Germany	Institute for Space Research	108
NASA, U.S.	Institute for Space Research	77
Harvard Smithsonian Ctr Astrophysics, U.S.	Institute for Space Research	54

Source: Web of Science Space Publications

Note: The table includes the top three international institutions with at least 50 publications for each case study organization.

3. Productivity

Table 8 shows the total number of publications for each organization in the case study sample. As noted in chapter 4, many papers do not identify a specific RAS institute with which the author is affiliated and therefore, the numbers of papers for Pulkovo Observatory, the Institute of Biomedical Problems, Lebedev Institute of Physics, the Institute of Solar-Terrestrial Physics, and the Institute of Space Research are probably underestimates. Based on the available data, Moscow State University, Kazan University, and the Institute for Space Research were the most productive institutions (with 3,466; 801; and 581 papers, respectively). The high scientific productivity of the case study institutions was not surprising, as it was one of the criteria for their selection.

Table 8. Productivity of Case Study Institutions

Institution	Number of Publications
MSU	3,466
Kazan	801
Institute of Space Research (RAS)	581
Lebedev Institute of Physics (RAS)	492
Pulkovo Observatory (RAS)	449
National Research Nuclear University	411
MIPT	391
Institute of Solar-Terrestrial Physics (RAS)	263
Bauman Moscow State Technical University	130
Lavochkin	113
Samara	105
MAI	95
Institute of Biomedical Problems (RAS)	20
Keldysh	14
Almaz-Antey	1

Source: Web of Science Space Publications

C. Quality of Education

Much of the information available on the quality of student preparation was not focused on the space sector. Nevertheless, the international rankings of Russian universities and studies of Russian undergraduate performance in STEM fields offer relevant insights on its competitiveness.

Several international rankings reveal that despite the efforts to improve the placement of Russian universities through the 5–100 Initiative, Moscow State University was the only institution that made it to the top 100, and only in some rating schemes (Table 9). A study by Russian scholars concluded that 75 percent of global rankings did not include Russian universities in the top 100 (Kuzminov et al. 2018). Interestingly, the *U.S. News* rankings of Russian universities on the subject of space are higher than the overall rankings for every institution that made it onto the list. For example, Moscow State University was ranked 77th in space science compared to 324th overall, and Moscow Institute of Physics and Technology was ranked 208th in space science compared to 438th overall (Table 9). Even though only one Russian university reached the top tier, several studies concluded that the 5–100 Initiative has had a significant positive effect on the international rankings and publication productivity of Russian universities (Turko et al. 2016; Poldin et al. 2017; Agasisti et al. 2019).

Table 9. Global Rankings of Russian Universities

	Times Higher Education 2022 (N=1600)	Shanghai 2021 (N=1000)	QS 2022 (N=1300)
MSU	158	97	74
MIPT	201–250	501–600	290
Higher School of Economics	301–350	601–700	305
St Petersburg Polytech University	301–350		393
National Research Nuclear University	401–500	701–800	319
Kazan	801–1000		347
Saint Petersburg State University	601–800	301–400	242
Novosibirsk State University	801–1000	601–700	246
Ural Federal University	1001–1200	701–800	351
Tomsk State University	601–800	901–1000	272
Bauman	801–1000		281

Sources: Times Higher Education 2022; Shanghai 2021; QS 2022

Table 10. Best Universities for Space Science

University	Overall	Space Science
MSU	324	77
MIPT	438	208
National Research Nuclear University	445	227
Kazan	824	157
Saint Petersburg State University	607	205

Source: U.S. News 2022
Note: (N=1,750)

A review of the literature identified several papers that compared the quality of undergraduate preparation in STEM fields across countries. One such study criticized the narrow, highly specialized nature of student training in engineering and other technical areas in Russia, which the authors saw as the legacy of the Soviet system that prepared students for a specific employer (Vlasenko et al. 2021). The authors of this study argued that in addition to instruction in the technical subjects, graduates should receive training in research skills and gain the ability to adapt to new requirements and tasks that were not offered in the Russian system. Another challenge identified in the paper included the paucity of faculty with experience in current scientific and technological problems in the space sector.

International comparative assessments of STEM undergraduate majors also concluded that Russian students receive a lower quality education, especially outside of a few top institutions (Loyalka et al. 2014). Even graduates from elite STEM programs performed worse than their peers in China and the United States when evaluated on the basis of critical thinking, mathematics, physics, and computer science skills (Loyalka et al. 2021; Loyalka et al. 2019). However, a space scientist from MIT interviewed for this study said that the quality of preparation of the half dozen Russian students he supervised was comparable to those of students from the top U.S. universities. However, he likely mentored an exceptional group.

Some published studies suggest that in contrast to the United States, STEM majors in Russia are not as prestigious as other fields. Students who enroll in these programs have lower scores on national examinations than students in some other programs. A report by the Center for Strategic Research and the Higher School of Economics in Moscow found that while Russia ranks first in the world in the share of scholarships awarded to engineering students, a quarter of those students had an average national exam score below 56 of 100, which the report notes is equivalent to a C grade in science and mathematics (Kuzminov et al. 2018). Another study concluded that attrition in Russia is higher in STEM than non-STEM fields, 25 percent to 20 percent (Kondratjeva et al. 2017). Rates of attrition from STEM programs observed in United States are lower; the difference between the two countries is statistically significant. The authors hypothesized that the higher rate of attrition in Russia may be due to lower selectivity—citing evidence from admissions monitoring that suggests that enrollees in most engineering programs in Russia have lower scores,[2]—challenging curriculum, or lack of academic support for struggling students in engineering departments. Vlasenko et al. (2021) pointed out that Russia graduates approximately 450,000 engineers per year—a significantly higher number than other countries (238,000 in the United States, 168,000 in Japan, and 149,000 in South Korea). However, 55 percent of Russian graduates work outside of the engineering profession (Vlasenko et al. 2021). Like other authors, Vlasenko et al. (2021) cited the lower prestige of the engineering profession in Russia compared to other countries, which they attributed to a demanding curriculum, but relatively lower pay for recent graduates.

In sum, STPI identified approximately 20 organizations as leaders in training students in space-adjacent fields and in conducting space R&D. Numerous degree programs at different educational levels are offered at these institutions. However, STEM degree programs attract weaker students in Russia than in other countries. International comparisons suggest that outside of a handful of top universities, the quality of STEM education in Russia lags behind that of other countries. More than half of Russian engineering graduates work outside of their profession.

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[2] The link to the data on exam scores provided by the authors was inaccessible in June 2022, and this claim could not be verified.

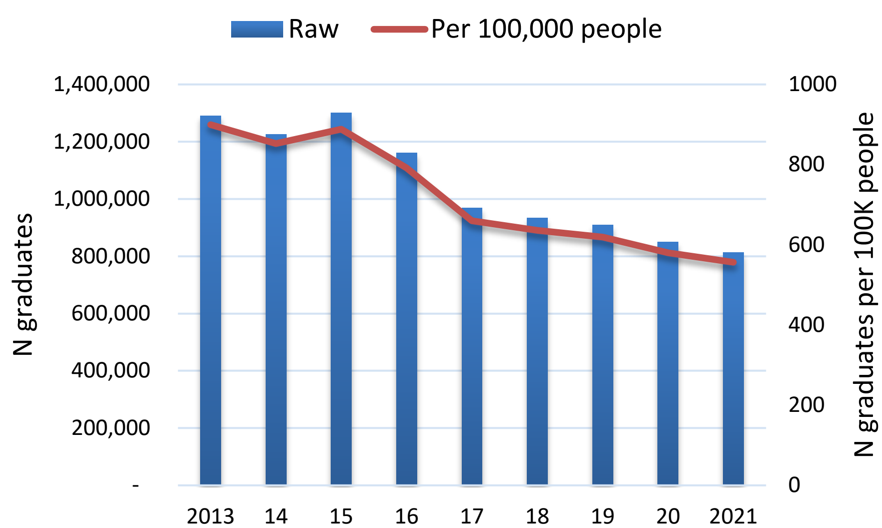
D. Trends in Space Education and Space Workforce

This section presents data on undergraduate and graduate degree attainment, the total number of graduates and scientists in different fields, the ages of candidate and doctorate degree holders, and employment by specialty. Whenever possible, the data were obtained for multiple time points to make it possible to conduct trend analysis and stratify the data by space, space-adjacent, other STEM, and non-STEM fields. Following educational and degree statistics, this section describes the flow of talent out of Russia and efforts by the Russian government to stop brain drain.

1. Undergraduate and Master's Degrees

Figure 15 shows the combined number of graduates with bachelors, specialist, and master's degrees over time and the numbers per 100,000 people. The data reveal a 37 percent decline in the total number of graduates with all degrees, from 1.3 million in 2013 to 800,000 in 2021. These changes were unrelated to changes in the size of Russia's population.

As discussed in the introduction, in 2003 Russia entered the Bologna process and a bachelor's degree was introduced as an alternative to a specialist degree. Analysis of graduation data shows that it took 10 years for the transition to begin: in 2013, the earliest available year, 86 percent of graduates still earned a specialist degree, but by 2017, the number had fallen to approximately 10 percent where it remains (Figure 6).



Source: Russian Ministry of Education for the number of graduates (translated from Russian) and OECD for total population.

Figure 15. Number of Graduates with Bachelor's, Specialist, and Master's Degrees, 2013–2021

Table 11 shows graduation statistics by field for undergraduate and master's degrees earned in 2013, 2017, and 2021. Graduates in all STEM fields represent about half of the total. The distribution of graduates in space and space-adjacent fields by type of degree was similar to other fields. Graduates in space plus space-adjacent fields made up 14 to 20 percent of the total, depending on the year; only 2,500–4,000 were in space fields. Between 2013 and 2021, the number of graduates in space and adjacent fields declined by 9 percent and in space alone by 30 percent.

Table 11. Number of Graduates with Bachelor's, Specialist, and Master's Degrees by Field

Field	2013	2017	2021
Space	4,022	2,576	2,799
Space-adjacent	175,879	170,595	160,725
Other STEM	195,817	137,680	122,990
Non-STEM	915,243	658,633	526,807
TOTAL	**1,290,961**	**969,484**	**813,321**

Source: Russian Ministry of Education. Translated from Russian.

STPI also examined the number of foreign-born students at Russian universities. In 2021, 53,350 of 732,139 accepted bachelor's degree students were foreign, representing 7 percent of the total. Table 12 lists all countries of origin with at least 1,000 students, which add up to nearly 50,000 of all 53,000 accepted. China and Egypt were the only countries on this list that were not members of the former Soviet Union, contributing only about 6,500 students in total.

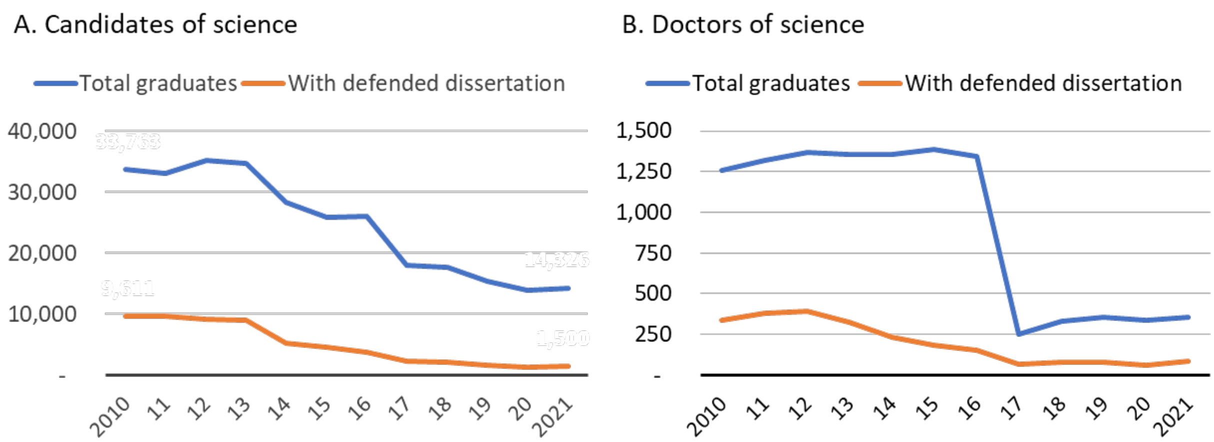
Table 12. Number of Foreign Students Accepted in Bachelor's Degree Programs

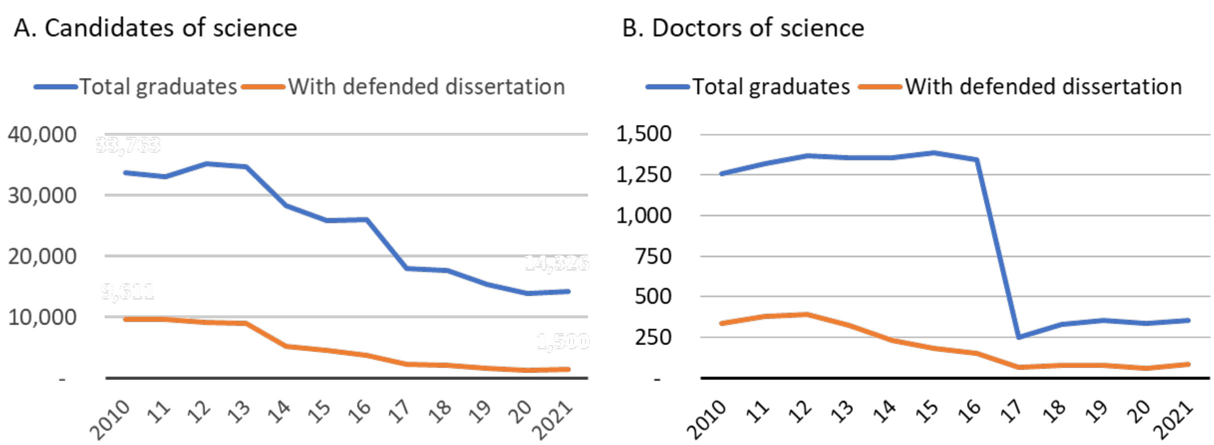
Country	Number of Enrolled Students
Uzbekistan	15,743
Kazakhstan	13,770
China	5,487
Tajikistan	5,329
Kirgizstan	2,230
Turkmenistan	2,177
Belorussia	1,734
Ukraine	1,184
Egypt	1,083
Azerbaijan	1,047

Source: Russian Ministry of Education. Translated from Russian

2. Candidate and Doctorate Degrees

STPI also examined the trends for individuals with advanced degrees for 2010–2021. Figure 16 shows a steep decline for these graduates: from approximately 34,000 to 14,000 (58 percent) for candidates of science without a defended dissertation and from 1,300 to 350 (72 percent) for doctors of science, also without a dissertation. The number of graduates with defended dissertations is much lower (1,500 for candidate and 87 for doctor of science in 2021), but the reason for this difference could not be determined from the data.





Source: Russian Statistical Service. Translated from Russian.

Figure 16. Number of Graduates with Candidate and Doctor of Science Degrees, 2010–2021

Data on the fields of candidate and doctorate degree recipients were coded and stratified in the four categories: space, space-adjacent, STEM, and non-STEM. The number of researchers with these degrees in space and space-adjacent fields was small and has declined over the past 3 years (Table 13). The percentage of graduates with degrees in space and space-adjacent fields was somewhat higher than for lower degrees, at 33 to 34 percent for candidates of science and 25 to 38 percent for doctors of science, depending on the reporting year.

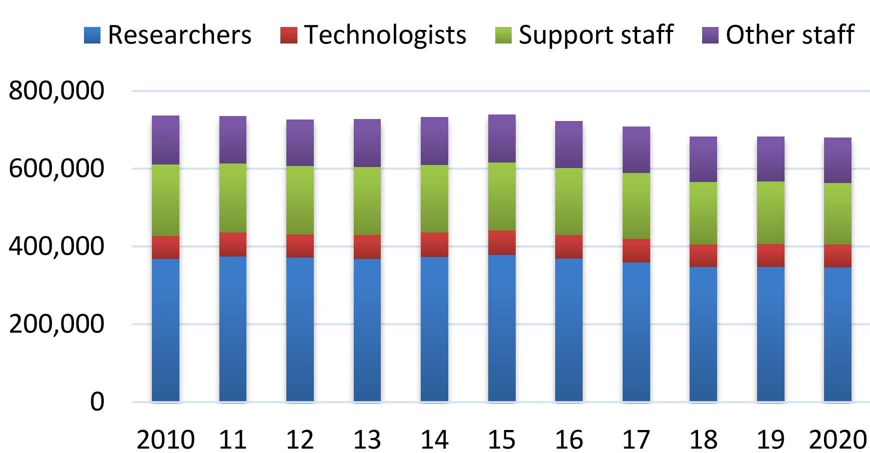
Table 13. Number of Graduates with Candidate and Doctor of Science Degrees by Field, without a Defended Dissertation

Field	Candidate of Science			Doctor of Science		
	2019	2020	2021	2019	2020	2021
Space	966	867	907	2	1	2
Space-adjacent	4,313	3,698	4,000	96	128	88
Other STEM	2,341	2,113	2,175	53	40	54
Non-STEM	7,833	7,279	7,244	205	170	207
TOTAL	**15,453**	**13,957**	**14,326**	**356**	**339**	**351***

Source: Russian Statistical Service. *Discrepancy in the data (the total is reported as 354). Translated from Russian.

3. 15,000 Size and Age of Russia's R&D Workforce

The Russian Statistical Service reports data on the workers engaged in R&D. Analysis of these data showed that the total number of these workers declined from 740,000 in 2010 to 680,000 in 2020, or by 8 percent (Figure 17). The decline from 2000 to 2020 was 25 percent. The workers were stratified into four groups: researchers—approximately 50 percent, support staff—25 percent, other staff—17 percent, and technologists—8 percent. The distribution by type of staff has remained fairly static over time. The decline in the number of workers between 2010 and 2020 was 6 percent for researchers, 14 percent for support staff, and 8 percent for other staff; the number of technologists remained unchanged.



Source: Russian Statistical Service. Translated from Russian.

Figure 17. Number of R&D Workers by Category, 2010–2020

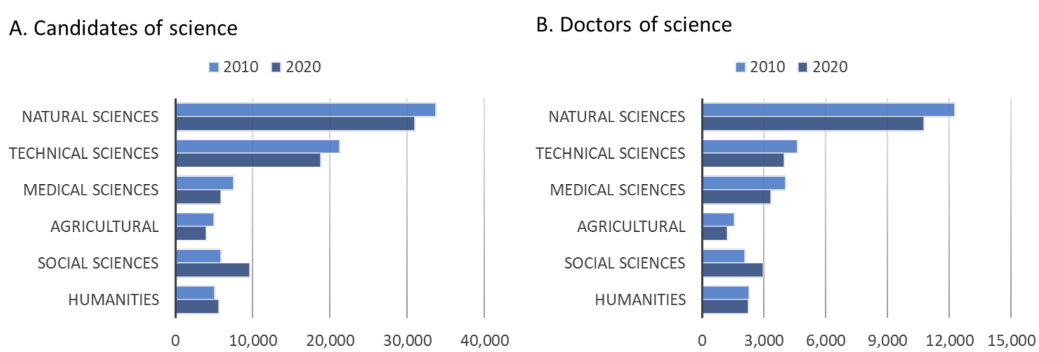
Table 14 shows that in 2020, of 346,497 researchers (about half of the total R&D workforce), 60 percent were in technical sciences, 23 percent in natural sciences, and the remainder was divided among the agricultural, medical, social sciences, and the humanities at 3 to 6 percent each. Of the total number of researchers, 29 percent had a candidate or doctorate degree. Degree attainment varied by field: it was the highest for the medical and social sciences and humanities with approximately 60 percent of researchers having earned a candidate or doctorate degree, followed by the natural sciences at 52 percent, and technical sciences at 11 percent. No explanation was provided in the data for how the technical sciences were defined.

Table 14. Distribution of Researchers by Field and Degree Attainment, 2020

Discipline	Total		With Advanced Degree	
	Number	Percent	Number	Percent
Natural sciences	80,966	23	41,716	52
Technical sciences	208,994	60	22,734	11
Medical sciences	14,584	4	9,173	63
Agricultural sciences	9,551	3	1,533	54
Social sciences	20,076	6	12,527	62
Humanities	12,326	4	7,839	64
Total	**346,497**	**100**	**99,122**	**29**

Source: Russian Statistical Service. Translated from Russian.

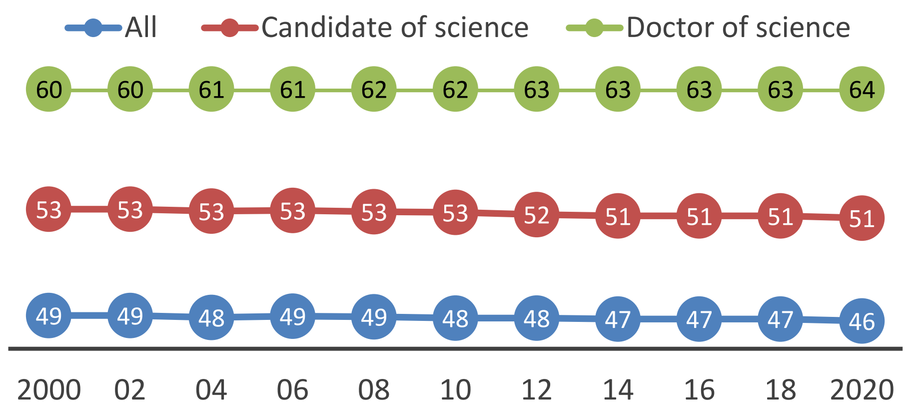
STPI also examined trends in advanced degrees over a 10-year period. Figure 18 shows that from 2010 to 2020 the total number of degrees awarded declined slightly for all STEM fields, with the largest change, in the natural sciences, at 8 percent for researchers with a candidate and 12 percent with a doctorate degree. No data were available on the number of R&D researchers in the space sector beyond what is described in the section above.



Source: Russian Statistical Service. Translated from Russian.

Figure 18. Number of Researchers with Advanced Degrees by Field, 2010 and 2020

STPI also examined trends in the average age of researchers. Based on data from the Russian Statistical Service, the average age in 2020 was 46 years for all researchers, 51 for candidates of science, and 64 for doctors of science (Figure 19). From 2010 to 2020, the average for all researchers fell by 3 years and the average age for candidates of science by 2 years. In contrast, the average age for doctors of science increased by 4 years. In 2020, 53 percent of candidates of science were younger than 50 years compared to 41 percent in 2010. In contrast, for doctors of science only 12 percent were younger than 50 at both points in time; the number of researchers who were older than 60 increased by 9 percent between 2010 and 2020, to 71 percent.



Source: Statistical Summary. Higher School of Economics. 2022. Translated from Russian.

Figure 19. Average Age of Researchers, 2010–2020

4. Shortages of Workers in the Defense and Space Sectors

Rimskaya (2014) stated that half of the 1,150 companies, research institutes, and other organizations in Russia's defense industry were experiencing shortages of workers. Based on a survey, the industry had a deficit of 17 percent of process engineers, a deficit of 22 percent of design engineers, and a 40 percent deficit of workers in various other specialties. Another paper found that "capacity utilization" in the space sector in 2015 was 50 percent and that the size of the workforce had declined by 15,000 since 2000, to 235,000 in 2017, of which 80 percent worked for entities within the United Rocket and Space Corporation, now Roscosmos (Aliberti et al. 2019). Rimskaya (2014) cited the secretary of *RKK Energia*, who said in 2015 that the space industry will need at least 100,000 highly qualified workers by 2025, approximately 42 percent of the 235,000 workers estimated to have been employed at the time. However, the space industry was struggling to attract new talent due to low pay and restrictions on international travel.

Furthermore, scientists, engineers, and managers represented only 37 percent of space talent, with the remaining 63 percent being lower-skilled workers. Almost half of the personnel were over 50 years old (Rimskaya 2014). Rimskaya (2014) unfavorably compared the age and professional characteristics of the Russian workforce in the defense sector to the United States, where scientists and engineers represented 69 percent of all workers, and only one-third were of the retirement age.

5. Efforts by the Russian Government to Mitigate Workforce Shortages in the Space Industry

Public statements and actions by the Russian government dating back a decade show an awareness of staffing problems in the space sector and attempts to mitigate it. In March 2013, Russian President Putin announced that the industry was experiencing an acute shortage of qualified personnel stemming from attrition and inadequate preparation (Interfax 2013). Following Putin's statement, several government initiatives were launched. These included a project to modernize the certification and credentialing of staff and initiatives to increase Russia's footprint in space R&D through two programs: "Space activities in Russia for 2013–2020" and "Strategies for the development of space activities in Russia until 2030 and further perspective."

At the same time, Roscosmos and the Ministry of Education signed an agreement to create a Space Science and Education Consortium. The consortium was composed of 33 universities (including Moscow State University, Bauman, and the Moscow Aviation Institute), 3 RAS institutes (the Academy of Cosmonautics, the Institute of Space Research, and the Academy of Systems Research), and 16 organizations from the space industry (Rimskaya et al. 2014; Aleksandrova 2017). The mission of the Consortium was to train and retrain specialists for the space industry, use the results of space activities to achieve national priorities, and conduct research that meets the needs of Roscosmos and its subsidiaries. However, in 2019 Putin declared that while the situation in the space sector was gradually improving, the need to recruit and retain talent remained (RIA.ru 2019).

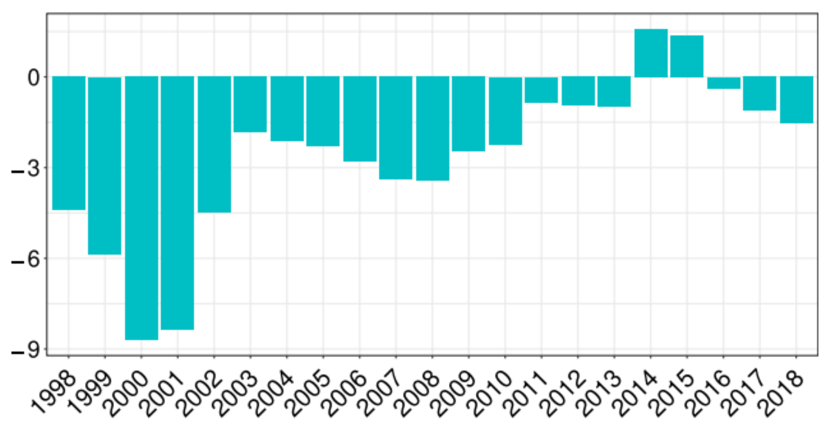
6. Brain Drain

The problem of brain drain—the emigration of Russian scientists to other countries—is openly acknowledged by the Russian government. In 2018, Deputy Prime Minister Dmitry Rogozin (subsequently the head of Roscosmos) spoke of Russia's brain drain and the resulting loss of Russian intellectual property. He called for measures to slow the outflow, such as establishing a network of scientific centers that would include leading Russian scholars (Interfax 2018).

In addition to these official statements, a number of studies have reported statistics on the outflow of talent from Russia going back to the 1990s. An article from 2018 noted that between 1990 and 2013 nearly 800,000 scientists left Russia, including 70 to 80 percent of its leading mathematicians and 50 percent of theoretical physicists (Studopedia 2018). An in-depth study of Russian emigration focused on what the authors called the "Putin Exodus." The study estimated that 1.6 to 2 million Russians left the country since 2000

(Herbst et al. 2019). They divided the exodus into two phases. The phase that began in 2012, corresponding to Putin's return to the presidency, has been driven by the worsening political situation and better educational opportunities elsewhere, rather than the economic necessity of earlier years. Emigrants who left the country since Putin's return included individuals in the middle- and upper-middle class, many with graduate degrees. This trend has not gone unnoticed in Russia: an editorial published in 2021 quoted the president of the Russian Academy of Sciences who said that the number of scientists who have left Russia has increased five-fold over the past 10 years, from 14,000 in 2012 to 70,000 in 2020 (RT 2021).

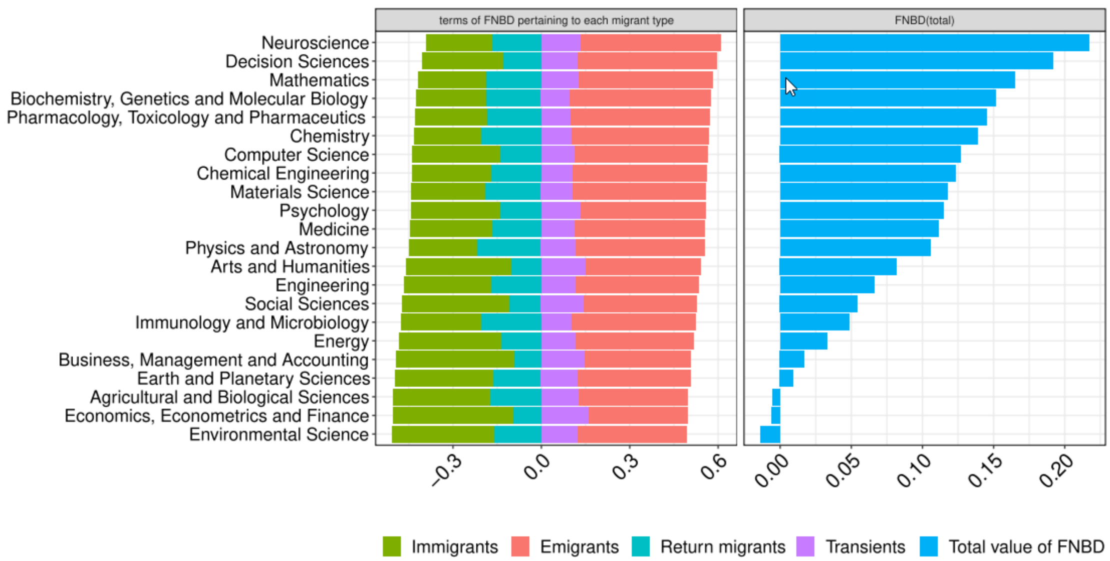
A recent study analyzed the patterns of emigration of Russian scientists between 1998 and 2018 using publications contained in the Scopus database (Subbotin et al. 2021). The authors found that the outflow of scientists peaked in the early 2000s, and slowed and even reversed in 2014 (Figure 20). This reversal probably resulted from several recent initiatives by the government to boost the scientific enterprise, such as the establishment of Skoltech in 2010 and the launch of the 5–100 Initiative in 2012. As can be seen from Figure 20, the trend began to reverse again in 2015, presumably after the annexation of Crimea by Russia.



Source: Subbotin 2021

Figure 20. Net Migration of Russian Scientists

Subbotin (2021) found that the loss of talent was largest in the biological sciences (neuroscience at 22 percent, biochemistry at 15 percent), chemistry and pharmacology (14 percent and 15 percent), and mathematics and decision science (16 percent and 19 percent, Figure 21). The loss in physics and astronomy was approximately 10 percent.

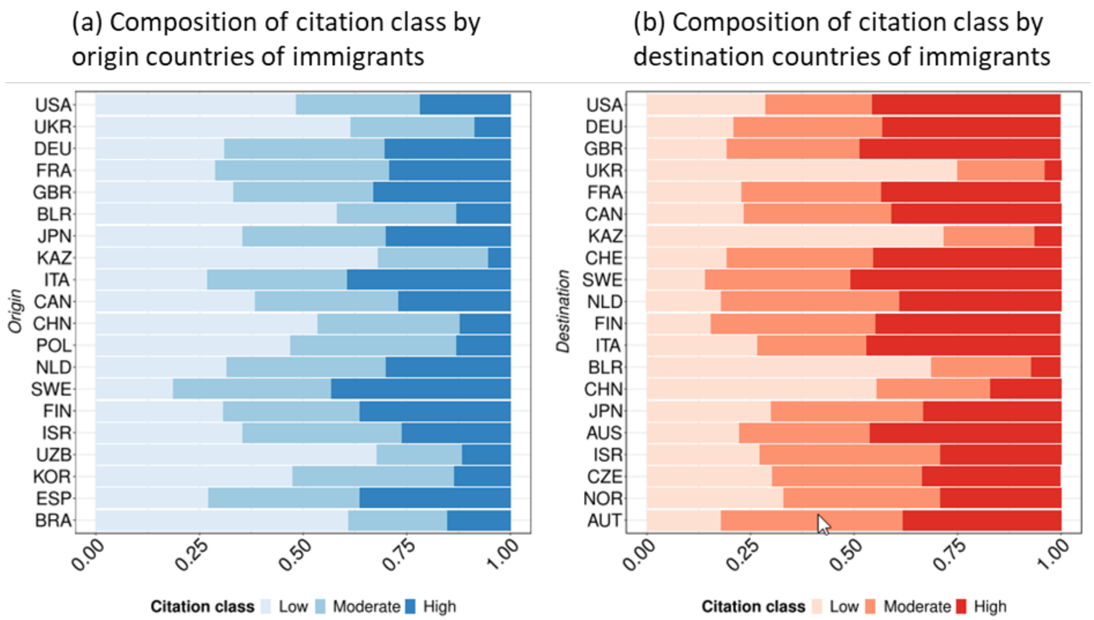


Source: Subbotin 2021

Note: FNBD stands for field-based brain drain.

Figure 21. Brain Drain by Field

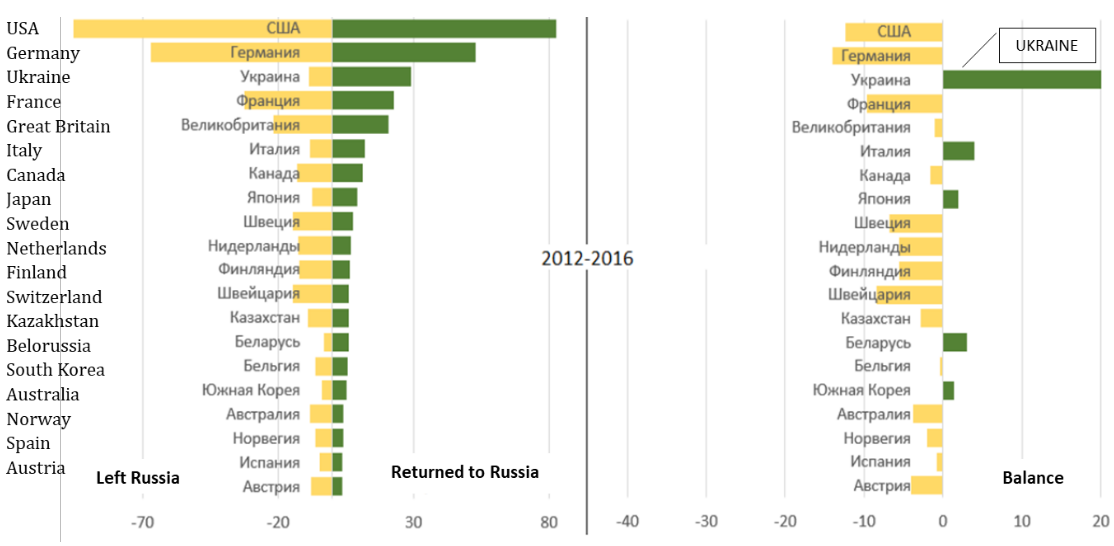
The study also examined the destinations of scientists who have left Russia, the countries of origin for immigrants to Russia, and the relative impact of their publications based on citation counts. Figure 22 shows that the United States was the most common country for both the origin and destination of scientists, and Ukraine was the second most common country of origin for scientists coming to Russia. The data also show that scientists who left Russia published papers that were more highly cited on average than those who remained. For example, nearly 50 percent of papers by scientists who went to the United States were highly cited compared to only 25 percent for those who immigrated to Russia from the United States.



Source: Subbotin 2021

Figure 22. Citation Impact for Scientists Who Have Immigrated to and Emigrated from Russia by Country of Origin and Destination

Subbotin (2021) found that Ukraine was the second most common country of origin for scientists immigrating to Russia, after the United States. The role of Ukraine in reversing Russia's brain drain emerged even more strongly from another study of migration patterns by Guskov (2021). As described in Figure 23, that study concluded that it was the supply of scientists from the Ukraine that helped compensate for the flow of Russian scientists to the United States and Western Europe.



Source: Guskov 2021. Translated from Russian.

Figure 23. The Flow of Workers in and out of Russia

7. Impact of the War with Ukraine

The invasion of Ukraine is likely to have a large impact on Russian science, although its scope is difficult to determine at this point in time. As the data presented in the previous section demonstrate, Ukraine was an important supplier of scientists to Russia, helping to mitigate brain drain to the West, but the fallout of the invasion is much more significant. The United States and European countries have severed or paused scientific partnerships with Russia, which lowers the quality of science as suggested by bibliometric measures. Anecdotal reports of professionals fleeing abroad appeared in open sources shortly after the invasion. An independent local newspaper reported that the Russian Association for Electronic Communications estimated that 50,000 to 70,000 information technology (IT) workers have left Russia since the outbreak of hostilities and the departure of an additional 70,000 to 100,000 is a possibility (East View On Demand 2022). In a sign that the Russian President is concerned about brain drain, the Russian government has responded by exempting technology workers from compulsory military service and offering them favorable mortgages and tax exemptions (Anderson 2022). It is unclear what, if any, effect these enticements will have on IT workers' decisions to leave the country, especially after the mobilization in September 2022 and a threat of future drafts into military service.

To encourage emigration from Russia, President Biden asked the United States Congress in 2022 to ease requirements for Russian scientists and engineers with graduate degrees who apply for employment in the United States. The request explicitly targeted several fields relevant to the space sector, including propulsion, nuclear engineering, hypersonics, autonomous systems and robotics, artificial intelligence, and space technologies and systems (The White House 2022d). The proposal was dropped to secure bipartisan agreement for supplementary funding to help Ukraine (Hudson 2022), but universities in other countries have allotted slots for fleeing Russian and Ukrainian scientists (Chawla 2022).

In sum, over the past 10 years the number of STEM graduates and the total number of scientists in Russia have declined for all degrees, in technical fields, and in the space sector, and it seems unlikely that the production of talent will meet the needs of the industry. The combination of the substantial brain drain of Russian scientists, low government investment in R&D, and the international isolation following the Ukraine invasion are likely to hamper Russia's ability to expand or possibly even maintain its position in space.

6. Conclusions

STPI drew on multiple open sources of data to understand the development of Russian space talent and characterize the state of the space workforce. The following conclusions emerged from the data:

- Russia's expenditures on space R&D are lower than those of other spacefaring nations; however, they represent a high fraction of its total R&D investments, highlighting the relative importance to the government.
- The educational system in Russia has undergone some important changes since the fall of the Soviet Union, which included steps toward integration with the EU. However, Russia never completed this transition and continues to rely on the educational approach inherited from the Soviet times that favors narrow specialization and inflexible curriculum. This system of education limits students' opportunities to explore their interests and change direction. Studies have found that Russian STEM students perform worse than foreign peers in technical subjects and have fewer transferrable skills.
- Russia maintains close connections between universities that train students, RAS institutes that conduct research, and Roscosmos that is the largest employer in the space sector. Some universities have established programs that directly supply graduates to the RAS space-related institutes and Roscosmos R&D units. Practical work at these organizations is an official part of student training.
- A mixed method strategy led to the identification of 74 organizations in Russia that play a role in developing and employing R&D workers in the space sector. These organizations include universities (primarily based in Moscow and Saint Petersburg but also in other regions of the country), several research institutes within RAS, and several units with the Russian space conglomerate Roscosmos. Most of the universities train students in many STEM (and non-STEM) fields, but a few are focused on space, aviation, and related fields.
- The Russian STEM workforce in general and in space specifically is shrinking. The number of students who have obtained undergraduate and graduate degrees and the number of STEM workers have declined in the past 10 years. In addition to producing fewer graduates, Russia has experienced significant brain drain, which began with the fall of the Soviet Union and continues to this day. The wave of emigration that began with Putin's return to power in 2012 included

well-educated and well-to-do citizens, who left the country for better opportunities rather than economic necessity. Among these emigrants are tens of thousands of scientists. Publication analysis revealed that scientists who left Russia published papers that are more highly cited than scientists who came to Russia.

- Analysis of papers published in space-related journals between 2005 and 2021 showed that 42 percent had a foreign co-author. Papers with Russian-only authors had significantly lower citation impact than papers with a foreign collaborator. Because of the geopolitical environment, Russian space scientists will have difficulty collaborating with foreign scientists. This will have a substantial impact on certain fields, such as astronomy and astrophysics, which tend to be especially collaborative.

In sum, even before the invasion of Ukraine, the Russian space workforce was on the downward trajectory, and the war is further eroding Russia's R&D ecosystem. Many factors lead to the conclusion that Russia will struggle to maintain its position in space and will probably be forced to downsize its R&D programs.

Appendix A.
Space Publications

STPI recorded publications in the Web of Science pertaining to “space topics” as listed by Clarivate.

STPI manually identified 112 journals as well as 51 conference proceedings indexed by Web of Science that covered a broad range of space topics. To identify relevant journals, STPI first used the categorization from Web of Science to filter all “space science” journals. Next, STPI worked through the engineering, social science, and Earth science filter to identify journals more relevant to aerospace engineering. In addition, STPI interrogated the journals published by relevant subject matter publishers, such as the American Institute of Aeronautics and Astronautics (AIAA) and Institute of Electrical and Electronics Engineers (IEEE), and identified relevant journals.

For conference proceedings, STPI used key word searches using space and aerospace topics that publish on space topics. From the identified “space” journals and conference proceedings, STPI examined all publication records published between January 2005 and February 2022.

The files were provided in XML format. STPI used the following search criteria to select publications of interest:

- All articles in the 112 space journals identified;
- All articles in the 51 space conference proceedings;
- #1 and #2 were amalgamated; and
- STPI limited the timeframe from 2005 to February 2022.

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Abbreviations

AIAA	American Institute of Aeronautics and Astronautics
CERN	European Organization for Nuclear Research
EU	European Union
FASO	Federal Agency for Scientific Organizations
FNBD	field-based brain drain
FSB	Federal Security Service of the Russian Federation
GDP	gross domestic product
IDA	Institute for Defense Analyses
IEEE	Institute of Electrical and Electronics Engineers
IMF	International Monetary Fund
ISR	Institute for Space Research
IT	information technology
MAI	Moscow Aviation Institute
MIPT	Moscow Institute of Physics and Technology
MIT	Massachusetts Institute of Technology
NASA	National Aeronautics and Space Administration
NSF	National Science Foundation
OECD	Organisation for Economic Co-operation and Development
OSTP	Office of Science and Technology Policy
R&D	research and development
RAS	Russian Academy of Sciences
STEM	science, technology, engineering, and mathematics
STPI	Science and Technology Policy Institute
UNESCO	United Nations Educational, Scientific and Cultural Organization
WoS	Web of Science
XML	Extensible Markup Language

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14. ABSTRACT
The Russian space program has been a source of inspiration and pride for generations of Russians. After the collapse of the Soviet Union, the space program continued, but not with the same level of success. Still today, Russia remains one of the leading spacefaring nations. The success of the space enterprise is tied closely with the skills and capabilities of the scientists and engineers who conduct research and development, manufacturing, and testing of space systems. This study examines the development and utilization of Russian space talent. Using a multi-method approach of literature review, education data analysis, and case studies, we found that Russian was losing talent due to factors such as brain drain and space was no longer held in the same esteem as the past. As a result, the number of students graduating with science, technology, engineering, and mathematics degrees, and those going into space fields was on the decline.

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