Part I

Accumulation and Application of Knowledge Gained Through Basic Research: To Enhance Japan's Research Capability

Chapter 1 Basic Research to Discover New Knowledge

The first chapter of Pat I Accumulation and Application of Knowledge Gained Through Basic Research takes a look back on the words of Nobel Prize-winning researchers from Japan to understand the essence and importance of basic research. Chapter 1 also analyzes the current status of Japan's fundamental capabilities for basic research (i.e. the number of papers, research funds, research personnel, research environment, etc.).

Section 1 Importance of Basic Research

Basic research is a research activity mainly focused on the exploration of truth, the clarification of basic principles, and the discovery, creation and accumulation of new knowledge. It is an effort to pioneer the frontiers of knowledge that no one has ever ventured into. In this quest, researchers keep devising original ideas and methods, gradually changing the unknown to the known through many instances of trial and error. For this reason, although the research period varies greatly depending on the research area,[1] basic research generally takes a longer time until a tangible result can be seen, and it is often difficult to immediately understand how the obtained result is useful. However, truth, basic principles, and new knowledge elucidated and created as a result of such research efforts are not only of great scientific value, but also have the potential to break the limits of existing technologies, create innovative products and services that have never existed before, and change our way of living and society in the most magnificent way.

Today, people are starting to embrace more diverse values and life paths, rather than solely focusing on economic growth and productivity. The new era of innovation and diversity has dawned, as we can see in the world's efforts for achieving SDGs[2] to solve global challenges, as well as in Japan's efforts to build what we call Society 5.0, a society where social challenges are tackled and new values are created by combining digital innovation with people's imaginative and creative power. The rise of innovative technologies, such as IoT[3] (information communication technology that interconnects objects via the Internet, which would be seen as an unimaginable science technological advancement in the eyes of people from the past if it had been realized), AI,[4] and genetic modification, is having a greater impact on economy, society and politics than ever. Japan is also shifting from a capital-intensive society, which is highly dependent on capital equipment with products being the main source of value to what is called a knowledge-intensive society, where all products and services have higher value-added through smartization.

In this knowledge-intensive society, future possibilities and options will vary depending on how much diverse and different knowledge we can draw together. For this reason, it is important to secure the diversity and depth of basic research[5] as an intellectual activity to pursue and create outstanding new ideas,

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1 Basic research in fields such as information science and life science only requires a relatively short period until its results are applied in society. For this reason, it is easier to raise research funds from private companies for projects in these fields. On the other hand, the results of basic research in fields such as mathematics and particle physics take a longer time to be applied in society.
2 Sustainable Development Goals
3 Internet of Things
4 Artificial Intelligence
5 Basic research is defined as "theoretical or experimental research conducted to form a hypothesis or theory or gain new knowledge about a phenomenon

and which involves the exploration of truth, the clarification of basic principles, and the discovery, creation and accumulation of new knowledge. In order to secure such diversity and depth, we need to support more original research projects built on researchers' intrinsic motive (i.e. the fundamental human desire to know). The creation and accumulation of new knowledge through basic research is what underpins social development. By applying the knowledge obtained in the real world, we could solve long-term social challenges, create new industries, and deliver completely new values to future society and people's lives. The significance of this type of research activity is higher than ever.

On the other hand, there are some worrying signs that could be seen as evidence of a decline in Japan's fundamental capability for science and technology and its position in the global research community, such as a decrease in Japan's share in the number of adjusted top 10% papers, which is one of the indicators of the quality of papers. In 2017, Nature also pointed out that Japanese scientific research activities seemed to have slowed down in recent years, with its international share of scientific papers decreasing.

Nobel Prize winners have also often pointed out the importance of basic research. For example, HONJO Tasuku, Distinguished Professor at Kyoto University, who discovered PD-1, a protein that brakes immune response, and won the Nobel Prize in Physiology or Medicine in 2018, said, "We still haven't figured out the entire picture of life science. In fields such as AI and rockets, researchers understand the overall picture of their fields and they can decide their goals and plan projects accordingly. On the other hand, it is very difficult to get a full picture of life science. I think there will be some serious consequences if we only promote the application of life science in such a situation." He also stressed the importance of conducting diverse basic research covering a wide range of topics, drawing on the analogy of mountaineering, saying, "I think it's nonsense to conduct an expedition without knowing which way is the right way to go or which mountain is important. Life science is now in the phase where we need to send many climbers to as many mountains as possible to understand what's there and which mountain is important."

HONJO Tasuku
Source: Kyoto University

or observable facts without directly aiming at any specific application or use." (Report on the Survey of Research and Development, Statistic Bureau, MIC). Research can be categorized according to two criteria: the nature of the project (basic, application, or development) and the reason for starting the project (academic, strategic, or by request). Basic research is defined by the first criterion, the nature of the project. It is "theoretical or experimental research conducted to form a hypothesis or theory or gain new knowledge about a phenomenon or observable facts without directly aiming at any specific application or use." On the other hand, academic research is defined by the second criterion: the reason for starting the research project. It is defined as "research commenced due to inherent motives of individual researchers and conducted under their own responsibilities, with an aim to explore truth, develop and apply scientific knowledge, or discover or solve challenges." (Mid- and Long-Term STI Policies in Japan: Towards Post-Fourth Science and Technology Basic Plan (Final Report), Comprehensive Policy Special Committee, Council for Science and Technology (CST), September 2015)

OHSUMI Yoshinori
Source: Tokyo Institute of Technology

OHSUMI Yoshinori, who elucidated one of the key molecular processes of the degradation mechanism in cells, called "autophagy," and won the Nobel Prize in Physiology or Medicine in 2016, said that he was "deeply concerned" about Japan's current situation where government's research grants are invested heavily in applied research for commercial and medical purposes. He also urged that "universities should secure an environment that allows researchers to conduct research purely for the sake of their curiosity, rather than for the sake of technology development. Curiosity forms precious seedlings that we should cultivate and nurture." He also stressed the importance of basic research, saying, "I am not saying that we should only conduct basic research. But I can say that no true progress will be achieved without basic research." While the government's policy for research and development is increasingly focused on exit strategies that look to practical application of research, Ohsumi emphasized that "basic research should not be evaluated according to the same criteria as applied research. Unpredictability is what makes basic research interesting."

KAJITA Takaaki
Source: The University of Tokyo

KAJITA Takaaki, who discovered for the first time in the world that neutrinos have mass and won the Nobel Prize in Physics in 2015, said, "Making an unexpected discovery that is different from the intended objective of the experiment is one of the most exciting things about scientific experiment. This research is not something that can be useful immediately, but it's something that expands the horizon of human knowledge." He also noted, "Basic research is not something that can be immediately used in our lives. Basic research is meaningful in two ways. Firstly, it will serve people's lives in a long term. Secondly, it adds to human intellectual property by leading us to the truth and a deeper understanding of the natural world."

TANAKA Koichi, who succeeded for the first time in the world to ionize proteins without destroying them and won the Nobel Prize in Chemistry in 2002 pointed out the importance of continuing basic research despite failures, saying, "A first-ever experiment often ends up in failure, but there also often lies an unexpected new opportunity. 99 out of 100 researchers may be devastated by such failure, but you must try and deeply understand what you have done in that experiment. You may be able to find a great opportunity that may lead to a one-in-a-million discovery that other disappointed researchers would have missed."

TANAKA Koichi
By courtesy of Shimadzu Corporation

Section 2 Current Situation of Japan's Fundamental Capability for Science and Technology

Basic research has come into the spotlight again following the receipt of the Nobel Prizes and as more people become aware of the current situation of Japan's fundamental capability for science and technology. Many have pointed out various challenges in continuously achieving desired performance in academic and basic research.

Can Japan continue to foster talented researchers with internationally outstanding, Nobel Prize-class achievements into the future? Can we continue to achieve outcomes in basic research that can bring completely new value to society and our lives in the future, while also solving long-term social challenges and creating new industries?

As a starting point for answering these questions, this section revisits an overview of research funds, personnel, and environment, while also looking at the number of papers using quantitative indicators that were also used in White Paper on Science and Technology 2018 to understand the quantity and quality of research projects in Japan. Through this, this section aims to draw a picture of the current situation of science and technology in Japan and issues surrounding it.

1 Number of Papers: Declining International Share and Stagnant Participation in Rising Research Areas

In recent years, the growth of the number of papers in Japan has stagnated, and its international share and ranking have declined. Japan's ranking for the number of adjusted top 10% papers[1] has fallen from the fourth to the ninth place over the past decade (Table 1-1-1).

1 The number of adjusted top 10% papers is the top 10% most cited papers in each field in each year, corrected to represent 1/10 of the real number of papers.

■Table 1-1-1/Number of papers and number of adjusted top 10% papers by country/region: top 10 countries/regions

All fields	2004-2006 (PY) (Average)		
	Number of papers		
Country/region name	Fractional counting		
	Number of papers	Share	Ranking
U.S.	228,849	25.7	1
Japan	67,696	7.6	2
China	63,296	7.1	3
Germany	53,648	6.0	4
UK	51,976	5.8	5
France	38,337	4.3	6
Italy	31,573	3.5	7
Canada	29,676	3.3	8
Spain	23,056	2.6	9
Rep. of Korea	22,584	2.5	10

All fields	2014-2016 (PY) (Average)		
	Number of papers		
Country/region name	Fractional counting		
	Number of papers	Share	Ranking
U.S.	273,858	19.3	1
China	246,099	17.4	2
Germany	65,115	4.6	3
Japan	63,330	4.5	4
UK	59,688	4.2	5
India	52,875	3.7	6
Rep. of Korea	46,522	3.3	7
France	45,337	3.2	8
Italy	44,450	3.1	9
Canada	39,674	2.8	10

All fields	2004-2006 (PY) (Average)		
	Number of adjusted top 10% papers		
Country/region name	Fractional counting		
	Number of papers	Share	Ranking
U.S.	34,127	38.4	1
UK	6,503	7.3	2
Germany	5,642	6.4	3
Japan	4,559	5.1	4
China	4,453	5.0	5
France	3,833	4.3	6
Canada	3,392	3.8	7
Italy	2,731	3.1	8
Netherland	2,146	2.4	9
Spain	2,093	2.4	10

All fields	2014-2016 (PY) (Average)		
	Number of adjusted top 10% papers		
Country/region name	Fractional counting		
	Number of papers	Share	Ranking
U.S.	38,736	27.4	1
China	24,136	17.0	2
UK	8,613	6.1	3
Germany	7,755	5.5	4
Italy	4,912	3.5	5
France	4,862	3.4	6
Australia	4,453	3.1	7
Canada	4,452	3.1	8
Japan	4,081	2.9	9
Spain	3,609	2.5	10

Note: The fractional counting method was used. Fraction counting is national counting weighted at the institutional level. For example, if a paper is co-authored by University A in Japan, University B in Japan, and University C in the United States, each institution is given a weight of one-third. The national total is two-thirds for Japan and one-third for the United States. In this manner, one paper is treated as one even if multiple national institutions are involved.

Source: NISTEP's "Japanese Science and Technology Indicators 2018" Research material 274 (August 2018) (Prepared by NISTEP based on Clarivate Analytics' Web of Science XML (SCIE, end of 2017 version))

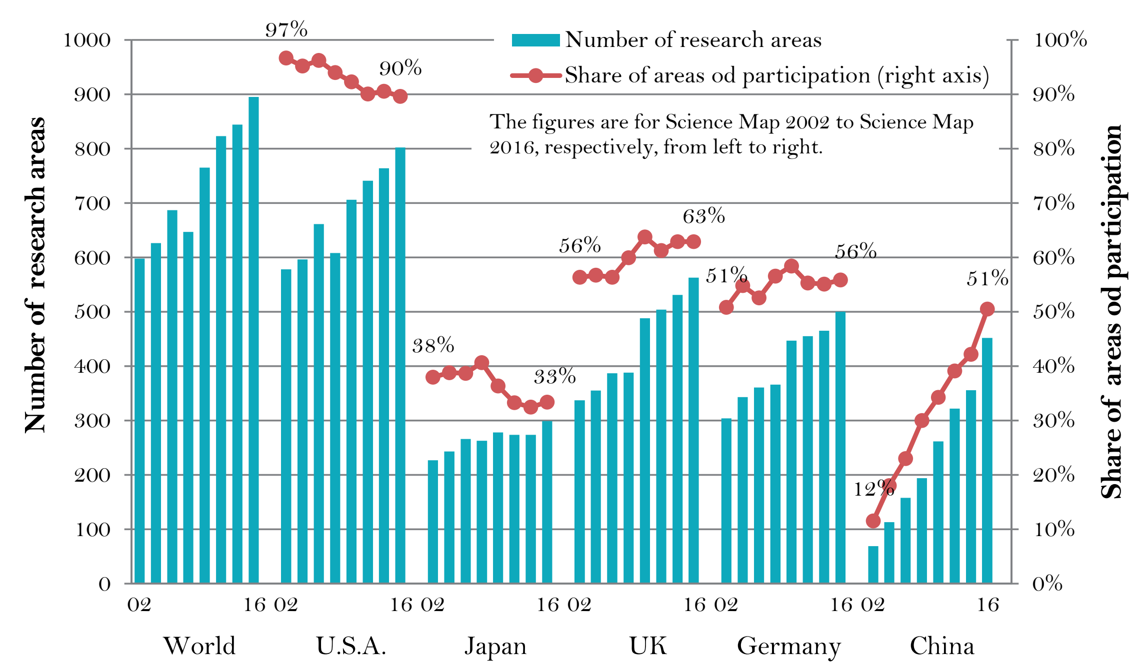
The NISTEP Science Map identifies research areas of international interest by co-citation analysis of the global top 1% most cited papers using a database of scientific papers.

As shown in Figure 1-1-2, the number of research areas of global interest in which countries are participating (hereinafter referred to as "areas of participation") increased from 598 (Science Map 2002) to 895 (Science Map 2016). The number of areas of participation is high among major countries. In particular, the United States participates in more than 90% of the global total number of research areas. The number of areas of participation also rose for the United Kingdom and Germany, both of which continued to participate in between 50% and 60% of the global total number of research areas. In the case of China, both the number of areas of participation and its share in the global total number of research areas increased.

On the other hand, the number of areas of participation for Japan has remained relatively low since the Science Map 2008. The share of areas of participation of Japan in the global total number of research areas fell by nine percentage points from 41% (Science Map 2008) to 32% (Science Map 2014). The share recovered by one percentage point to 33% in the Science Map 2016. This was due to an increase in the number of areas of participation as a result of co-authoring in international joint projects.[1]

1 NISTEP, Science Map 2016, October 2018.

■Figure 1-1-2/Major countries' number of areas of participation and share of the number in the global total number of research areas



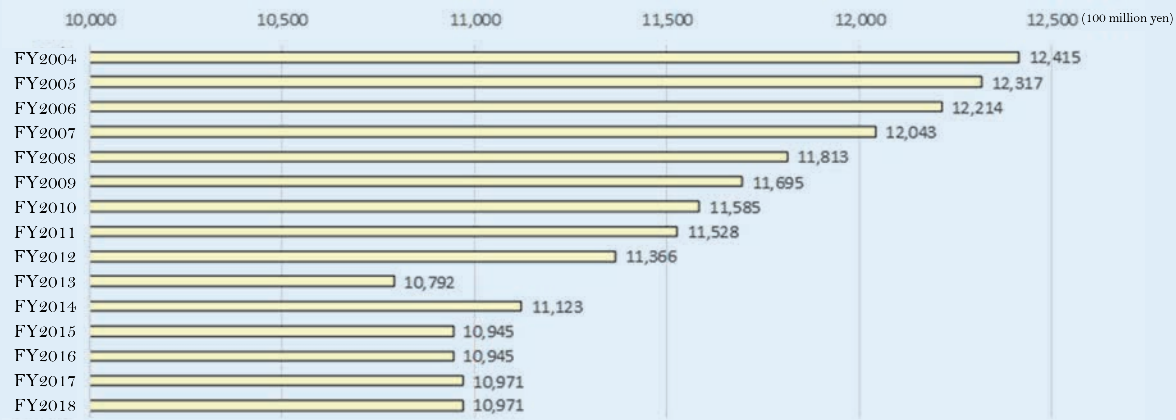
Note: When the core papers constituting a research area include one or more papers produced in a relevant country, the country is assumed to be participating in the area.
Source: NISTEP's "Science Map 2016" NISTEP REPORT No.178 (October 2018) (Prepared by NISTEP based on Clarivate Analytics' Essential Science Indicators (NISTEP ver.) and Web of Science XML (SCIE, end of 2017 ver.))

2 Research Funds: Importance of Basic Research Funds to Support Basic Research

Next, we will look at changes in basic research funds, which are used to continually and stably support research and education carried out at national and private universities and national research and development agencies.

Operating expense grants for national university corporations have stayed at almost the same level in the past few years, although they had decreased significantly before that since FY2004 (Figure 1-1-3). Current expenditure grants for private universities have also been hovering at the same level in recent years albeit at a lower level compared to FY2004 (Figure 1-1-4). Operating expense grants for national R&D agencies had temporarily decreased until it started to increase again in FY2015 (Figure 1-1-5).

Figure 1-1-3/Changes in operating expense grants for national university corporations



Note: The figures are the initial budget amounts of the general account of individual fiscal years. The budget for FY2017 includes funds to enhance the function of national university corporations (4.5 billion yen). The budget for FY2018 includes funds to enhance the function of national university corporations (8.9 billion yen).

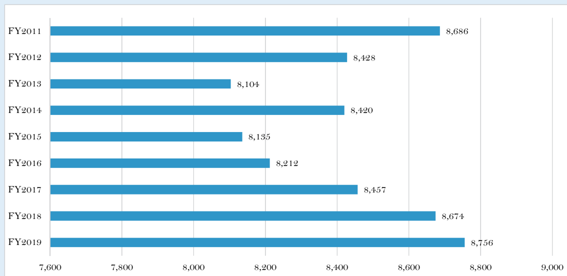
Source: MEXT

Figure 1-1-4/Changes in current expenditure grants for private universities, etc.

Note: The figures are the initial budget amounts of the general account of individual fiscal years.

Source: MEXT

Figure1-1-5/Changes in operating expense grants for national R&D agencies



Note: The figures are the total initial budget amounts of the General Account and Special Account of individual fiscal years. Corporations that have been merged into other corporations were also tabulated.

Source: Prepared by MEXT based on "Explanation of the Budget and the Fiscal Investment and Loan Program" (MOF).

Meanwhile, competitive funds,[1] which are another main resource that supports research along with the abovementioned basic research funds, should be used in an even more effective and efficient way that allows us to maximize Japan's research capability and outcomes. At the same time, both basic research funds and competitive funds need to be reformed and enhanced. Government grants should be allocated in a way that achieves the optimal combination of these two types of funds, while also ensuring that basic research funds support relatively new projects until they take off and become ready to obtain competitive funds.

Figure 1-1-6 shows an international comparison of the share of the higher education and government

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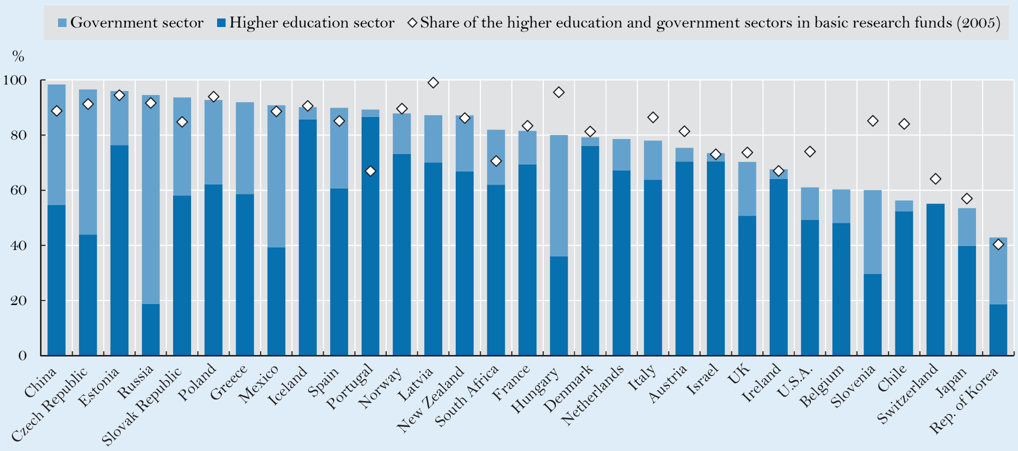
1 A competitive fund is a type of research fund. Each competitive research fund accepts applications of R&D plans from a variety of entities. Research funds are granted to projects that qualified as a result of screening by multiple experts and judges.

sectors in basic research funds provided by four domestic sectors (higher education, government, corporate, and private non-profit sectors) in OECD[1] countries. The figure for Japan stands at 53.4%. The contribution of the higher education and government sectors to basic research funds is lower in Japan than other major countries.

■Figure 1-1-6/Share of the higher education and government sectors in basic research funds



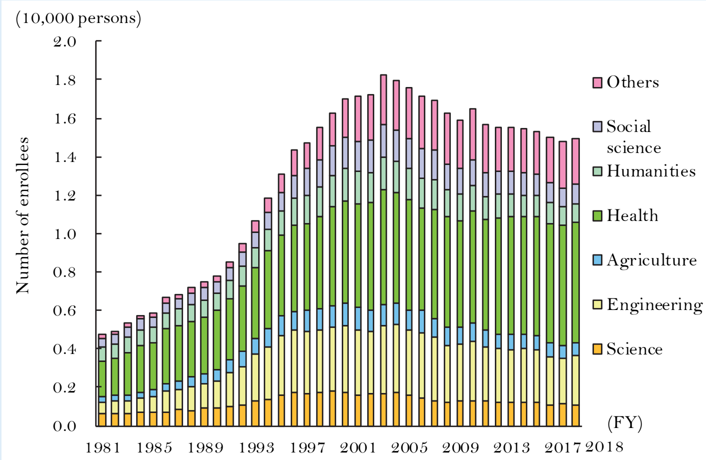
Source: Prepared by MEXT based on OECD Science, Technology and Industry Scoreboard 2017 (November 2017)

3 Research Personnel: Decreasing Number of Newly Enrolled Doctoral Students

The most common major of doctoral students newly enrolled in 2018 was health science (6,271 students; 42.1%), followed by engineering (2,562 students; 17.2%). There also were some 1,000 students each in the fields of science, humanities, and social science. Compared to FY2003, the total number of newly enrolled doctoral students has decreased, while the departmental number increased only in health science (Figure 1-1-7).

1 Organisation for Economic Co-operation and Development

■Figure 1-1-7/Changes in the departmental number of newly enrolled doctoral students



Increase or decrease from FY2003 to FY2018	
Science	-568
Engineering	-1009
Agriculture	-412
Health	270
Humanities	-696
Social science	-687
Others	-227

Note: Health: Medicine, dentistry, pharmacy, nursing science, etc. Others: Mercantile marine, household management, education, art, etc.

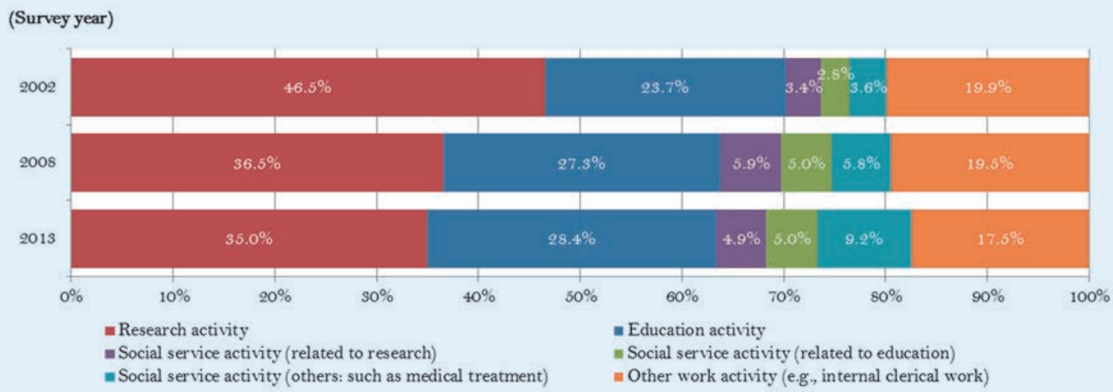
Source: Prepared by NISTEP, based on MEXT's "Report on School Basic Survey" and "Japanese Science and Technology Indicators 2018" (research material 274, August 2018)

4 Research Environment: International Comparison of Research Hours and the Number of Research Assistants

Factors related to research environment, such as research hours, research team, and research management, are also important for researchers.

Figure 1-1-8 shows changes in the proportion of hours faculty staff spend on research. The average proportion of research hours in all research areas fell from 46.5% in 2002 over the following six years to 36.5% in 2008, and it declined slightly over the following five years, to 35.0% in 2013. On the other hand, the share of hours spent on education activity increased from 23.7% in 2002 over the following 11 years to 28.4% in 2013. In addition, regarding the number of hours spent on social service activity as a social contribution, the number of hours spent on all categories of social service activity—including research-related activity, such as providing technical consultations concerning the use of research results; education-related activity, such as giving lectures open to the general public; and other activity, such as medical treatment—increased steeply between 2002 and 2008. Between 2008 and 2013, in particular, the number of hours spent on other social service activity, such as medical treatment, increased steeply. The number of hours spent on other work activity (e.g., internal clerical work) declined slightly.

■Figure 1-1-8/Changes in the share of research hours spent by university and college faculty members

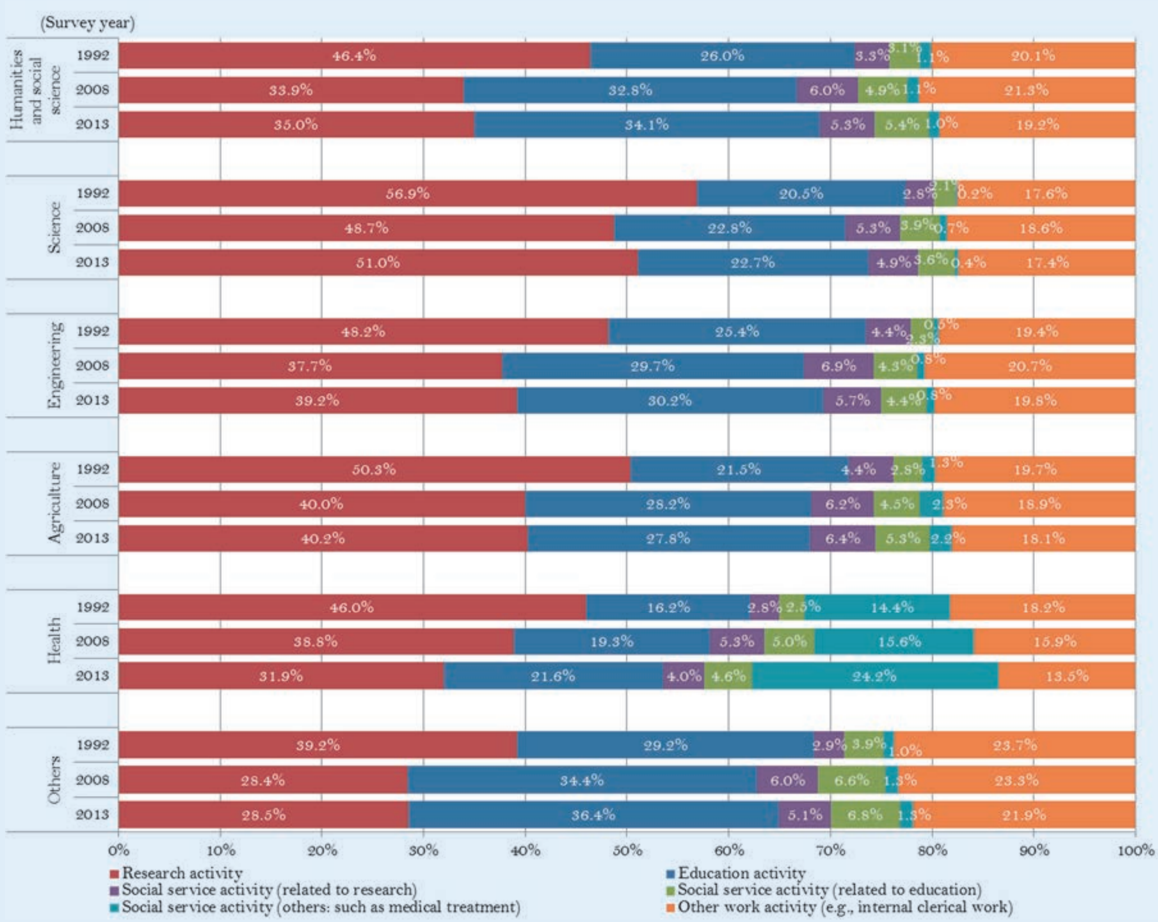


Source: Prepared by MEXT based on *Changes in the Ratio of Time Spent on Work Activities by University & College Faculty Members — A Comparison of results of the 'Survey of Full-time Equivalency Data at Universities and College' of 2002, 2008 and 2013* (Research Material-236) (April 2015), NISTEP.

The change in the share of hours spent on work activities differs across academic fields.[1] Between 2002 and 2008, the number of research hours declined in all academic fields. This is considered to be due to increases in the number of hours spent on education and social service activities by university and college faculty members. Between 2008 and 2013, in the field of healthcare, the share of research hours declined from 38.8% to 31.9%, while the share of hours spent on social service activity (other activity, such as medical treatment) increased significantly. In fields other than healthcare, between 2008 and 2013, the share of research hours increased slightly in all fields, indicating a marginal improvement in the situation (Figure 1-1-9). As the number of faculty members in the field of healthcare accounts for around 30% of the total number of faculty members, the change in the share of research hours in this field has a large impact on the share of the overall number of research hours spent by faculty members.

1 This is a classification of organizations of universities and other institutions by academic research field based on the *Report on the Survey of Research and Development*, which is prepared every year by the Statistics Bureau of the MIC.

■Figure 1-1-9/Changes in the share of hours spent on work activities by university and college faculty members by academic field



Source: *Changes in the Ratio of Time Spent on Work Activities by University & College Faculty Members — A Comparison of results of the 'Survey of Full-time Equivalency Data at Universities and College' of 2002, 2008 and 2013* (Research Material-236) (April 2015), NISTEP

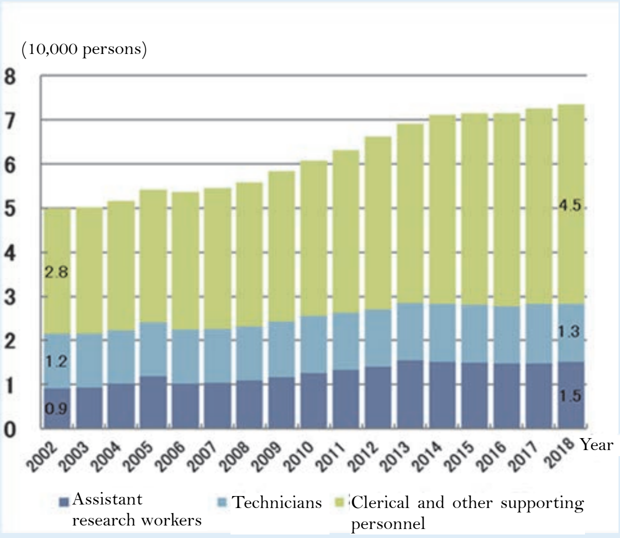
Allocation of research assistants[1] who assist faculty members' research activities and research-related clerical work is another important factor in securing the research environment for researchers.

Regarding research assistants at universities and colleges, clerical and other supporting personnel accounted for the largest number, 45,000 personnel, in 2018, followed by assistant research workers, totaling 15,000, and technicians, 13,000. While the numbers of clerical and other supporting personnel and assistant research workers are increasing, the number of technicians has remained almost flat (Figure 1-1-10).

On the whole, the number of research assistants at universities and colleges is trending upward. However, the number of research assistants per researcher in Japan is small compared with the numbers in other countries (Figure 1-1-11).

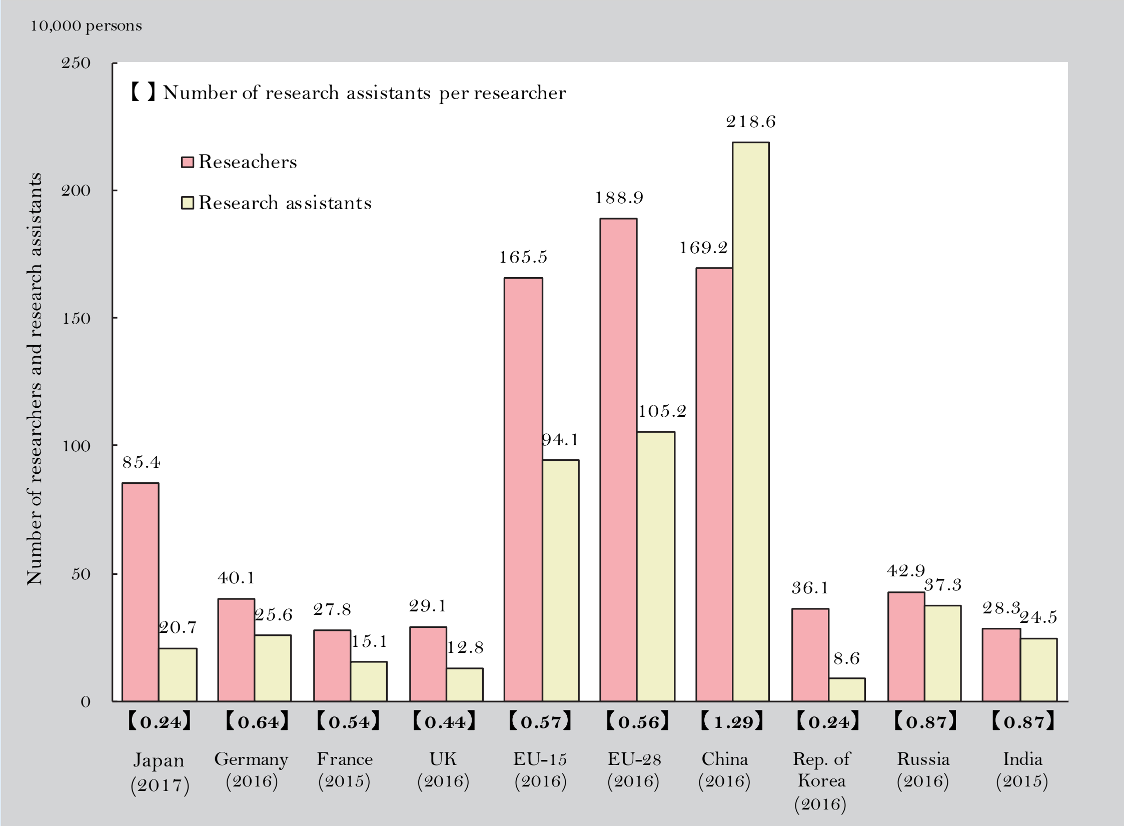
1 MEXT defines research assistants as those who are categorized as assistant research workers, technicians, and clerical and other supporting personnel in the Report on the Survey of Research and Development published by the Statistics Bureau, MIC. According to the definitions in the Report, assistant research workers are persons who assist researchers and who are engaged in research activities under their direction and supervision. Technicians are persons who provide research-related technical services under the supervision and direction of researchers and assistant research workers. Clerical and other supporting personnel are those who engage in research-related work concerning general affairs and accounting.

■Figure 1-1-10/Changes in the number of research assistants at universities, etc. in Japan



Source: Prepared by MEXT based on Japanese Science and Technology Indicators 2018, Research Material-274 (August 2018), NISTEP, and Report on the Survey of Research and Development, the Statistic Bureau, MIC

■Figure 1-1-11/The number of research assistants per researcher in major countries



Notes: 1. The number of research assistants per researcher was calculated by MEXT based on the numbers of researchers and research assistants.
2. The figures for all countries include the numbers in humanities/social sciences fields.
3. Research assistants include personnel supporting research activity, personnel providing research-related technical services and personnel engaging in research-related clerical work. In Japan research assistants are classified into assistant research workers, technicians, and clerical and other supporting personnel.
4. The figures for Germany are estimated and provisional ones.
5. The number of researchers in the United Kingdom is an estimated, provisional figure, and the number of research assistants is underrepresented.
6. The figures for the EU are those estimated by the OECD.

Source: Japan: *Report on the Survey of Research and Development*, the Statistics Bureau of the MIC; India: UNESCO Institute for Statistics S&T database; other countries: Prepared by MEXT based on *Main Science and Technology Indicators* (2018/1), OECD (Indicators of science and technology, 2018 ver.)

As mentioned in Section 1, innovative scientific discoveries are products of researchers' constant efforts and their ingenious and novel ideas. It is important to create an environment where researchers can fully exert their abilities. However, as seen in Section 2, Japan's fundamental capabilities for science and technology are declining in relative terms as we can see in quantitative indicators for the number of papers, research funds, research personnel, and research environment.

How should Japan interpret this situation and which way should it head next? In Chapter 2, we will look at case examples to show the value that basic research can deliver to society and technologies that underpin basic research, with a hope that this will be an opportunity for people to reflect on the meaning and importance of the accumulation and application of knowledge gained through basic research.