Chapter 2 Opening up Possibilities for Innovation through Science and Technology

Various factors are related to the achievement of innovation. Among those, the production of superior results with Science and Technology (S&T) is essential as a basis of innovation. The enhancement of S&T capabilities is indispensable to the nation's commitment to innovative achievement.

Section 1 Activating Science and Technology Activities for Achieving Innovation

1 Vitalization of R&D Activities

In Chapter 1, we note that papers produced in Japan have been decreasing both in quality and in quantity when compared with other major countries. Here, we analyze some of the trends regarding the R&D activities, which include the trend of internationally co-authored papers - as defined below - and the state of participation in research areas drawing international attention (hot research areas). Also discussed are new fields and inter-/multidisciplinary fields, as well as the current commitment to high-risk research that goes beyond a mere extension of previous research. Then we discuss a course of action to be promoted and new ways of evaluating R&D programs.

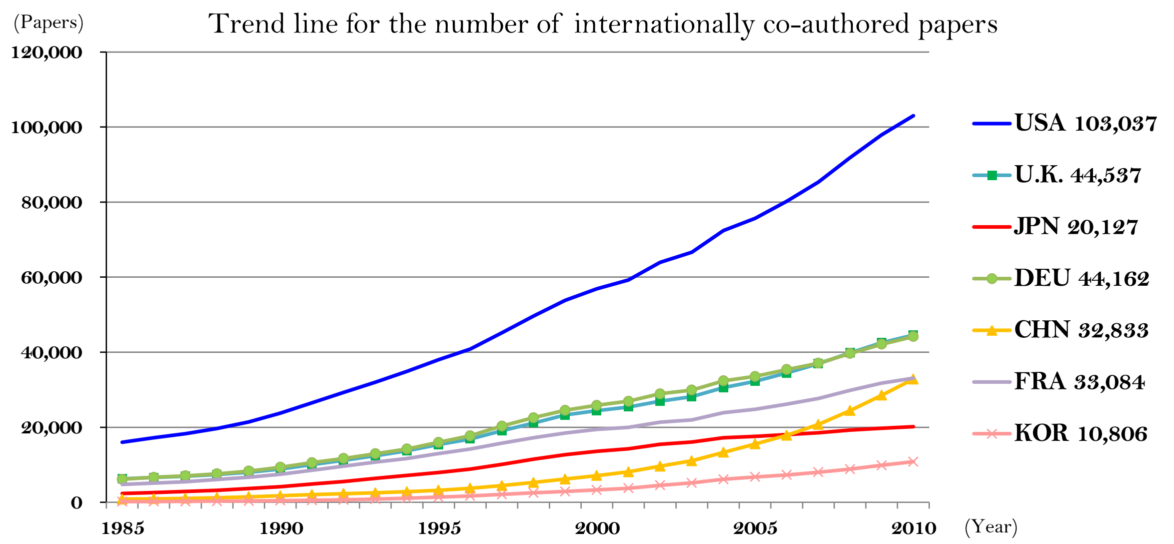
(1) Challenges over the quality of research activities in Japan

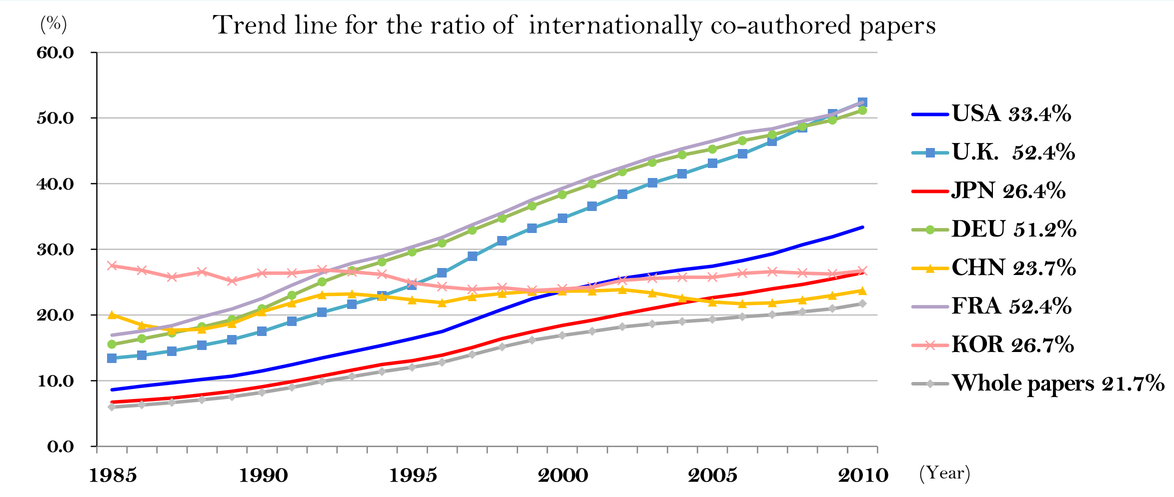
1) Internationally co-authored papers

We analyze the issue that the rate of increase in the number of all research papers and quality research papers produced in Japan are lower than those in other major countries from the view point of papers jointly written by researchers who belong to different organizations in different countries (hereinafter referred to as "internationally co-authored papers").

In recent years, the number of internationally co-authored papers has increased sharply in each country, mainly because of active brain circulation (Figure 1-2-1, top). The number of internationally co-authored papers has increased in Japan, which accounts for 26.4% of all the papers published in 2010. However, the graph shows that it is much lower than the percentages of internationally co-authored papers produced in other countries: 52.4% in U.K., 52.4% in France, and 51.2% in Germany (Figure 1-2-1, bottom).

Figure 1-2-1 / Trend Lines for the Number and Ratio of Internationally Co-authored Papers





Notes: 1. Analysis based on integer count of Article, Article & Proceedings, Letters, Notes, and Reviews Indicates 3 year moving average

2. NISTEP calculated based on "Web of Science" powered by Thomson Reuters.

Source: NISTEP, "Science Research Benchmarking 2012" (February 2013)

In order to grasp the attribute of internationally co-authored papers, we focus on the number of citations - one of the indicator detecting research quality - and make a comparison of the number of citations per paper between internationally co-authored papers and papers produced by domestic institutions only (hereinafter referred to as "domestic papers") (Table 1-2-2). According to the table, in Japan, for example, the average number of citations per domestic paper is 11.7 while that of an internationally co-authored paper is 20.5, showing that internationally co-authored papers are cited more frequently than domestic papers. This tendency is common in other major countries as well. The result indicates that internationally co-authored papers are more likely to be of higher quality in general.

Table 1-2-2 / Number of Citations per Paper of Domestic Papers and Internationally Co-authored Papers

Country	Domestic papers	Internationally Co-authored papers
U.S.	20.9	25.6
U.K.	16.0	25.7
Japan	11.7	20.5
Germany	14.5	23.7
China	9.1	16.5
France	13.1	22.1
Korea	9.3	16.3

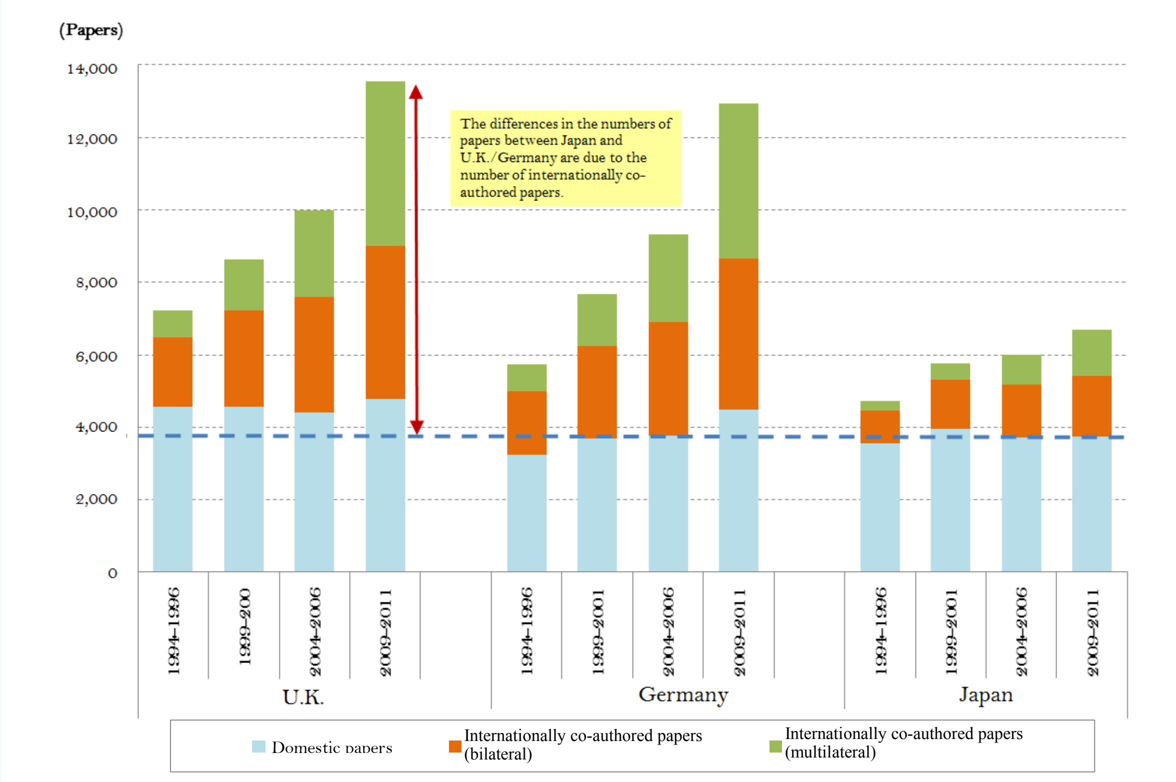
Notes: 1. Analysis based on integer whole counting of Article, Article & Proceedings (use of article), Letters, Notes, and Reviews
Indicates 3 year moving average
2. Numerical are Average of citation, which are calculated average at the end of 2011 for papers published between 2004 and 2006
3. Compiled by NISTEP based on Thomson Reuters "Web of Science".

Source: Created by MEXT based on NISTEP, "Science Research Benchmarking 2012" (February 2013)

Next, we show the construction of adjusted numbers of top 10% highly cited papers[1], which were produced in Japan, U.K., and Germany. The papers are divided into domestic papers and internationally co-authored papers for comparison (Figure 1-2-3). The graph shows: 1) the numbers of domestic papers produced in Japan, U.K., and Germany are almost similar and have not changed much in the past 15 years; 2) while the number of internationally co-authored papers produced in U.K. and Germany have greatly increased, the number of internationally co-authored papers produced in Japan has increased only slightly, which accounts for the difference in the total adjusted number of top 10% highly cited papers.

1 The number of adjusted top 10% highly cited papers is the number of papers obtained by selecting the papers whose number of citations ranks in the top ten percent in each field each year, and then adjusting the number so that the actual number will be one tenth of the number of the papers.

Figure 1-2-3 / Changes the in Construction of Internationally Co-authored Papers and Domestically authored Papers in Adjusted Top 10% Highly Cited, Produced in Japan, U.K., and Germany



Notes:
1. Analysis based on whole counting method of Article, Article & Proceedings, Letters, Notes, and Reviews
2. Indicates 3 year moving average
3. "Internationally co-authored paper" means a paper published by researchers belonging different research institutes/universities in different countries.
4. Compiled by NISTEP based on Thomson Reuters "Web of Science".

Source: NISTEP "Benchmarking Scientific Research 2012" (March 2013)

One of the reasons why Japan shows the lower rate of increasing adjusted number of top10 % highly cited papers rather than other countries is that Japan has been failing to keep up with the present, worldwide increase in internationally co-authored papers. In addition, we assume that because internationally co-authored papers are generally cited more often than domestic papers, the number of excellent papers produced in Japan has been stagnant when compared with those produced in other countries.

For these reasons, it is strongly suggested that promoting international collaborative research conducted by excellent researchers will be one of the measures that will help to revitalize Japan's research activities.

2) Hot Research areas – research areas attracting international attention

(Inter-/multidisciplinary areas)

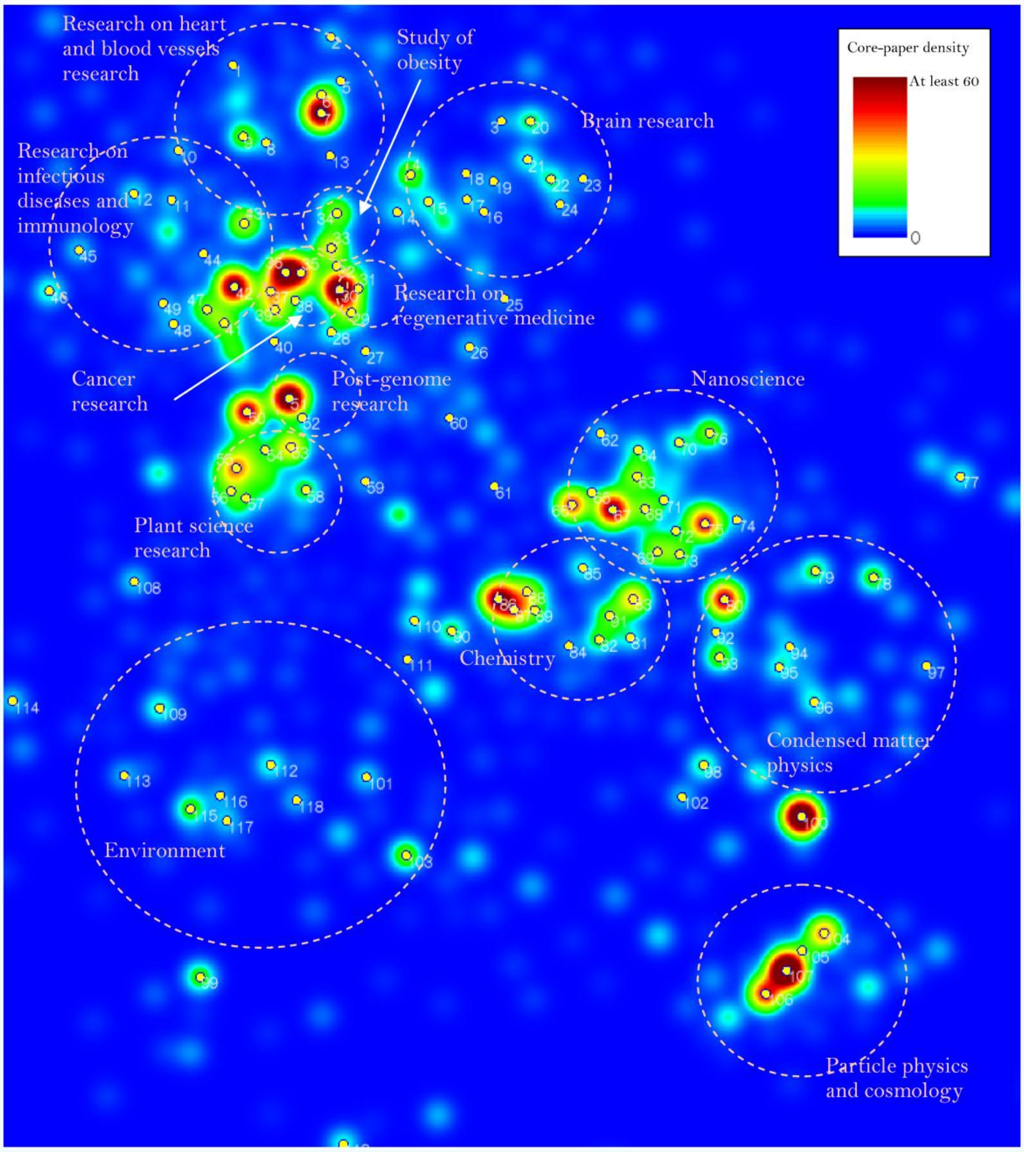
The Council for Science and Technology (CST) submitted a report, entitled "What the Science and

Technology Policies Should Be in the Future in View of the Great East Japan Earthquake (suggestion)," to the government on January 17, 2013. The suggestion took into account the understanding that the Great East Japan Earthquake had revealed a lack of research integrating knowledge from a wide range of research fields, including the humanities and the social sciences. This was especially true in regard to Seismology in Japan. The suggestion thus pointed out the need for interdisciplinary research and collaboration/integration among different research fields in order to find, identify and solve complex problems. Here, we look at the trend of such research from a viewpoint of developing new fields for exploration.

As noted in Chapter 1, the number of papers produced in the world and collected in the scientific papers database[1] is growing year after year. These days, more than 1.1 million papers are collected in a year. By analyzing those papers, some research areas, which draw attention to academia can be found because highly cited papers have been actively published. The National Institute of Science and Technology Policy (NISTEP) identified 647 research areas by clustering highly cited papers (the top one percent of papers in each field, each year from 2003 to 2008) and by visualizing the relationships among those hot areas in the Science Map (Figure 1-2-4). The hot research areas include the research area; "Regenerative Medicine and Stem Cell Research," based on the core papers produced by Shinya Yamanaka M.D., Ph.D., a professor at Kyoto University and the research area; "Iron-based Superconductors," based on the core papers produced by Professor Hideo Hosono at the Tokyo Institute of Technology.

1 Thomson Reuters, Web of Science, related to natural sciences

Figure 1-2-4 / Science Map 2008



Notes: 1. Since the map was created using the gravity model, what carries meaning is not determined by what is located on top, bottom, left or right, but by how the positions are located relative to each other. In the map shown above, life sciences are placed in the upper left, and particle physics and cosmology are placed in the lower right.

2. A yellow spot indicates the center of a research area. A dotted circle indicates a rough approximation of a group of research areas.

Source: NISTEP, "Science Map 2008" (May 2010)

One of the characteristics of hot research areas is that many of them are inter-/multidisciplinary areas. Hot Research areas are classified into two groups; one is a group of research areas constructed by papers of a single research field (clinical medicine, chemistry, physics, etc.) and another is group of inter-/multidisciplinary areas constructed by papers of that are related to multiple research fields (Table 1-2-5). Clinical medicine has the largest number of research areas (116 areas) when considering the hot research areas focused on a single research field, but inter-/multidisciplinary research areas have even more than that (151 areas). It is also observed that research activities are more robust in inter-

/multidisciplinary areas (yielding relatively new research results) than in the hot research areas which are focused on a single research field (refer to Column 1-1).

Table 1-2-5 / The State of Japan's Participation in Hot Research Areas Drawing International Attention

Field	Number of Relevant research areas	Japan's participation	U.K.'s participation	Germany's participation
Total	**647**	**263**	**388**	**366**
Inter-/multidisciplinary areas	151	66	96	81
Clinical medicine	116	41	82	75
Chemistry	64	28	32	38
Physics	61	35	39	39
Engineering	44	9	12	14
Plant and animal sciences	36	20	24	24
Geosciences	30	19	26	21
Neuroscience and behavioristics	17	12	12	12
Computer science	17	4	8	10
Environment /Ecology	15	4	10	9
Mathematics	14	1	3	6
Social science, general	13	1	7	5
Psychiatry/psychology	12	2	7	6
Biology and biochemistry	11	6	4	6
Economics and business	9	0	5	1
Space sciences	8	3	7	7
Agricultural science	8	3	4	4
Materials sciences	7	4	1	3
Molecular biology & genetics	5	2	4	3
Microbiology	5	1	4	0
Pharmaceutical science/toxicology	3	1	0	1
Immunology	1	1	1	1

Note: NISTEP calculated based on Thomson Reuters "Essential Science Indicators"
Source: NISTEP, "Science Map 2008" (May 2010)

Column 1-1

Characteristics of Interdisciplinary/Multidisciplinary Research Areas

The Science Map has been published every two years since 2002 when it was first published. Examining its changes gives us a glimpse of the dynamics of scientific researches. The procedure of making the map is as follows. At first degrees of intensity of the relationships among the top 1% of highly-cited papers are calculated (Co-citation relationships: if a group of papers is simultaneously cited by another paper multiple times, then the group of papers are defined as having similarity and a relationship regarding their contents.), then based on these degrees, a two-step clustering is performed; as a first step, top 1% highly cited papers are clustered to obtain research fronts (including multiple top 1% highly cited papers) and then they are clustered to extract research areas (including multiple research fronts).

Studying Science Maps from 2002 to 2008 and comparing these maps lead us to understand the characteristics of inter-/multidisciplinary research areas. The number of research areas, the average number of research fronts included in the research areas, the number of research fronts with rapidly increased citations, and the number of research fronts in the latest year are summarized in a table below. First, the table shows that inter-/multidisciplinary research areas' share of all research areas has remained nearly constant, at approximately 20%, since 2002. Second, the inter-/multidisciplinary research areas exceed the average of research areas focused on a single discipline in all of the following three numbers: the average number of research fronts included in the research areas, the number of research fronts with rapidly increasing numbers of citations (refer to Note 1 of the table), and the number of research fronts in the latest year (refer to Note 2 of the table). This indicates that inter-/multidisciplinary research areas involve a large number of topics, show a significant increase in citations, and yield relatively new research results. In other words, inter-/multidisciplinary areas are research areas where intellectual production is more active than in other research areas.

In Science Map 2002, inter-/multidisciplinary areas are concentrated around research field in the life- sciences, but in the Science Map of 2008, inter-/multidisciplinary areas spread across the map, and combinations between the life-science area and non-life-science area increased. The result shows that continuous changes in quality have been taking place in inter- /multidisciplinary areas.

Science Map 2002

	Number of research areas	Average number of research fronts	Average number of research fronts with rapidly increased citations	Average number of research fronts in the latest year
Interdisciplinary/multidisciplinary areas	150	6.86	0.75	0.59
Research areas focused on a single discipline	448	5.33	0.51	0.40
Total	598	5.71	0.57	0.45

Science Map 2004

	Number of research areas	Average number of research fronts	Average number of research fronts with rapidly increased citations	Average number of research fronts in the latest year
Interdisciplinary/multidisciplinary areas	137	7.63	0.90	0.66
Research areas focused on a single discipline	489	5.02	0.52	0.38
Total	626	5.59	0.60	0.45

Science Map 2006

	Number of research areas	Average number of research fronts	Average number of research fronts with rapidly increased citations	Average number of research fronts in the latest year
Interdisciplinary/multidisciplinary areas	146	6.75	0.73	0.53
Research areas focused on a single discipline	541	4.74	0.48	0.38
Total	687	5.17	0.54	0.41

Science Map 2008

	Number of research areas	Average number of research fronts	Average number of research fronts with rapidly increased citations	Average number of research fronts in the latest year
Interdisciplinary/multidisciplinary areas	151	7.21	0.89	0.69
Research areas focused on a single discipline	496	5.14	0.55	0.49
Total	647	5.62	0.63	0.54

Notes: 1. Research fronts with rapidly increased citations were determined by the following method: When the slope of the regression line of each year's increase and decrease in the number of citations per core paper in each research front exceeds the mean slope in each field, and when the average year of the publication of core papers is in the latter two years of the analysis period (in and after 2007 in the case of Science Map 2008), such research fronts were extracted as research fronts with rapidly increased citations.

2. Research fronts in the latest year are the research fronts that appeared most recently during the last year of the analysis period (2008 in the case of Science Map 2008).

3. NISTEP calculated based on Thomson Reuters "Essential Science Indicators"

Source: NISTEP, "Science Map 2008" (May 2010)

In addition, these maps show that the citation relationships between condensed matter physics and particle physics/cosmology and between the life-sciences and nano-science have grown in the past several years, indicating that the spread, integration and fusion of knowledge have been occurring.

We then compare the numbers of hot research areas and having the characteristics as mentioned above, and compare the amount of participation in Japan, U.K., and Germany as based on the numbers in these areas (Table 1-2-5). Participation of specific country is recognized when a research paper ranking in the top one percent has been presented in that country. Japan participated in 263 of a possible 647 research areas, while U.K. and Germany participated in 388 and 366 total areas, respectively—a big difference in the number of participation areas. The number of participation areas can be considered as the coverage rate of present-day sciences, and thus the number raises the possibility that the diversity of research in Japan may have failed to fully respond to scientific trends throughout the rest of the world; thus Japan fell behind U.K. and Germany, especially when considering Japan's participation in inter-/multidisciplinary areas and clinical medicine.

In some research areas, research papers from Japan made up a large share of all research papers: 52%[1] of papers on "novel electronic order in high-temperature superconductivity," in physics, and 42% of papers on the "production of interferon by innate immunity" in inter-/multidisciplinary areas. However, Japan only had an 8% share of all research areas, which was considerably less than that of the U.S. (58%), Germany (14%), and U.K. (13%). Furthermore, China (7%) was narrowing the gap.

(Directions of international collaboration that vary with research areas)

Another characteristic of the hot research areas is that many internationally co-authored papers are produced in these areas (Table 1-2-6). The number of internationally co-authored papers has been steadily increasing worldwide. This trend is especially stronger in hot research areas. International

1 The share of research papers Japanese researchers are involved in writing of the top 1%1% papers in the area

collaboration, however, varies with the research field a research area belongs to.

For example, in the environmental/earth sciences, which have a relatively high rate of international co-authorship, researchers need to collect and analyze data through international cooperation in order to advance their research. For this reason, in many cases, they have elaborate networks of co-authored papers. In such areas, it may be effective for researchers to participate in international networks to which they themselves contribute by providing data and other resources.

Also in physics, especially in the research areas of particle physics, international co-authorship networks of research institutions have been constructed mainly by research institutions with large facilities, such as the Super-Kamiokande (the University of Tokyo), the KamLAND (Tohoku University), the Fermi National Accelerator Laboratory (U.S.), the European Organization for Nuclear Research (CERN), and the Istituto Nazionale di Fisica Nucleare (Italy). In such areas, research institutions develop large-scale, world-leading facilities by themselves or they actively contribute to the development and operation of those facilities as important factors when participating in research networks.

On the other hand, in the research areas of chemistry, there is a relatively low rate of international co-authorship, and co-authorship networks of research institutions are fragmented into many small networks consisting of a small number of research institutions. Each institution may independently conduct research, even when the research is on a topic closely related to the topics other institutions are working on, and they may exchange knowledge by citing research papers. In such areas, it may be important for a country to have research institutions with a certain level of research capabilities inside the country, rather than to form international networks.

As we have seen above, the characteristics of co-authorship networks within research institutions varies depending on the research area, the research methods and according to the conditions of international competition. Thus, the direction of international collaboration should vary according to the specificity of a research area. It is therefore important to take into account the characteristics of a co-authorship network in each research area, and also to consider the conditions of international competition when promoting the construction of a human-resources network or a research network with overseas research institutions. Then, we must evaluate whether or not the collaboration will be promoted through an effective approach for research development.

Table 1-2-6 / The Rate of International Co-authored Papers in Hot Research Areas Drawing International Attention

Field of hot research area	Rate of International co-authored papers	Field of hot research area	Rate of International Co-authored papers
Agricultural sciences	38.8%	Mathematics	31.6%
Biology/biochemistry	30.8%	Microbiology	33.3%
Chemistry	17.8%	Molecular biology/genetics	35.1%
Clinical medicine	40.4%	Neuroscience/behavioristic	35.6%
Computer science	27.8%	Pharmacology/toxicology	20.0%
Economics and business administration	22.9%	Physics	45.2%
Engineering	23.4%	Plant/animal sciences	40.4%
Environmental science/ecology	44.7%	Psychiatry/psychology	34.2%
Earth science	54.5%	Social science/general	25.0%
Immunology	33.3%	Space sciences	74.6%
Materials science	23.2%	Inter-/multidisciplinary areas	36.4%
		Total	36.1%

Notes: 1. The percentage of international co-authored papers of in each research area was calculated after classifying all research areas into fields to which they belong and into interdisciplinary/multidisciplinary areas. Fields with a higher percentage of international co-authorship than the overall average in each map are colored.
2. NISTEP calculated based on Thomson Reuters “Essential Science Indicators”

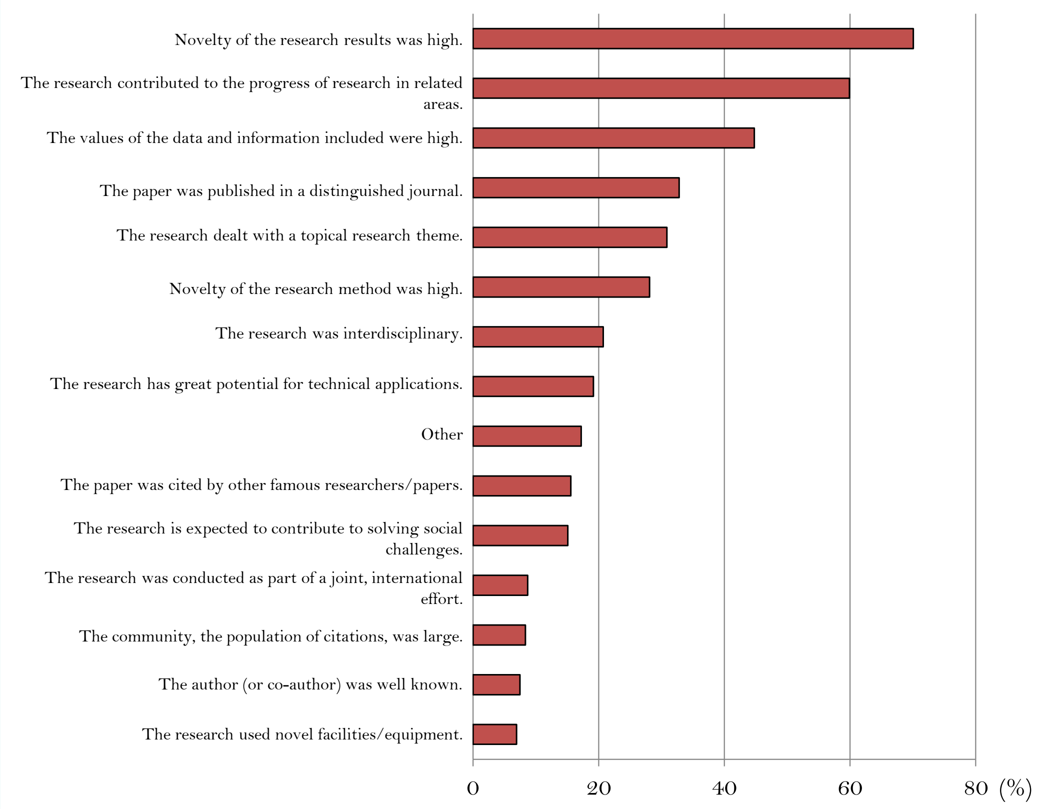
Source: NISTEP, “Science Map 2008” (May 2010)

3) High-risk research

Determination and a willingness to take on challenges in unique R&D are important factors for S&T activities. Some research involves a high risk of failing to achieve a goal, but if it is successful, the results may have social, economic or scientific impacts, and they are likely to greatly advance the research area. Other research is full of new ideas or attractiveness, but it requires the denial of existing concepts and the adoption of new methods. These types of research are drawing attention and are called “high-risk research.”

According to a survey of researchers who produced top 1% highly cited papers, the factors that influenced the citation frequency of their papers included: a high novelty of research results; the inclusion of valuable data and information; a high novelty of research methods; and interdisciplinary research (Figure 1-2-7). The results indicate that it is important to promote high-risk research with many uncertainties in order to seek results that will enable Japan to take a giant leap forward, rather than research that is merely an extension of current research or research that produces easily predictable results.

Figure 1-2-7 / Factors that Influence Citation Frequency (a Survey of Authors)



Source: NISTEP, "Knowledge Creation Process in Science: Basic findings from the large-scale survey of researchers in Japan" (November 2010)

CST pointed out the need for measures that include the government's support for high-risk research in the report entitled "What the Science and Technology Policies Should be in the Future in View of the Great East Japan Earthquake (suggestion)" (January 2013)[1]. Based on the suggestion, CST also decided to work out concrete measures concerning the "promotion of high-novelty and high-risk research" as stated in the "Basic Policy to Drastically Strengthen R&D Capacity in Japan" (April 2013).

On the other hand, in a questionnaire to the members of the SCJ, 40 percent of the respondents answered that they did not think research objects were evaluated based on the risks and uncertainties of the research[2]. In addition, according to the researchers' answers to the question about the diversity of basic research, when comparing the current condition of research sites with previous conditions, they think that the number of challenging research projects that could create new research areas has decreased and that the number of research projects that are most likely to produce results or that can

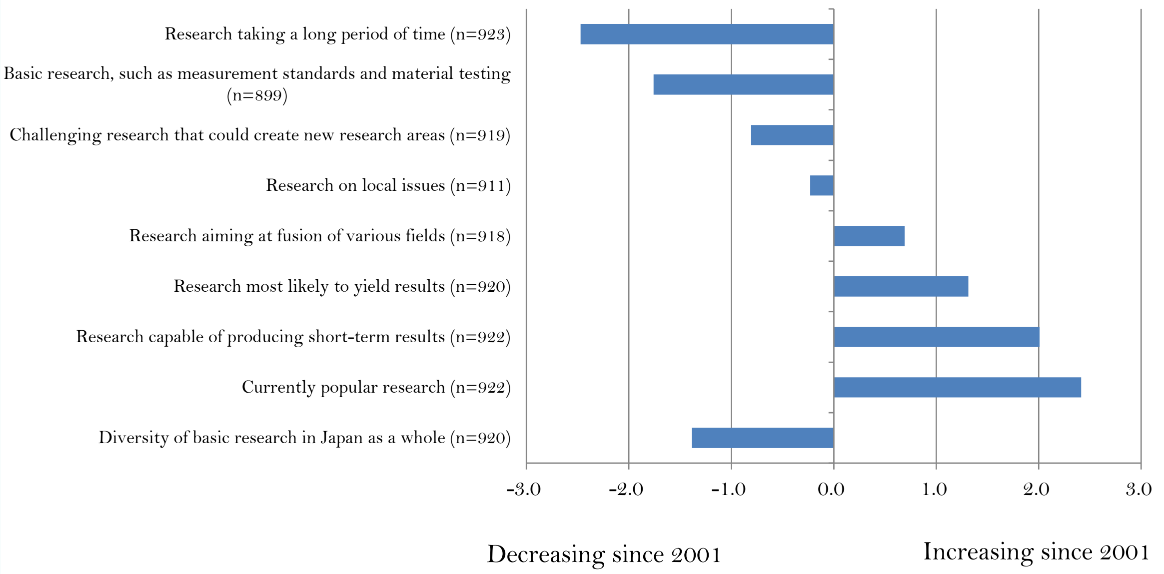
1 The CST's suggestion pointed out: "The industrial circles should be requested to get involved in and contribute to research issues with high-risks but with significant effects expected, in accordance with research phases. The government should provide multilayered and intense support for the promotion of R&D, for the development and strategic use of advanced research facilities, for the establishment of management systems in cooperation among industry, government and academia, and for the invitation and training of talents for advanced research. It is important to promote these efforts in order to break down the walls between existing areas and organizations, to overcome the "Death Valley" for R&D, and to establish a large R&D center with international competitiveness in cooperation among industry, government and academia."

2 SCJ's "How Japan's research evaluation system should be" (October 2012)

produce results in a short period has increased (Figure 1-2-8).

These answers make us fear that, while the importance of high-risk research is growing these days in Japan, the number of research projects that have a stronger possibility of yielding results or that can produce short-term results are increasing when compared with the number of challenging research projects. For this reason, preparations of measures that encourage researchers to tackle high-risk research through competitive funding, or by other means, are more urgent than before.

Figure 1-2-8 / Survey of Researchers on the Diversity of Basic Research



Source: NISTEP, "Analytical Report for 2010 Expert Survey on Japanese S&T System and S&T Activities by Fields" (May 2011)

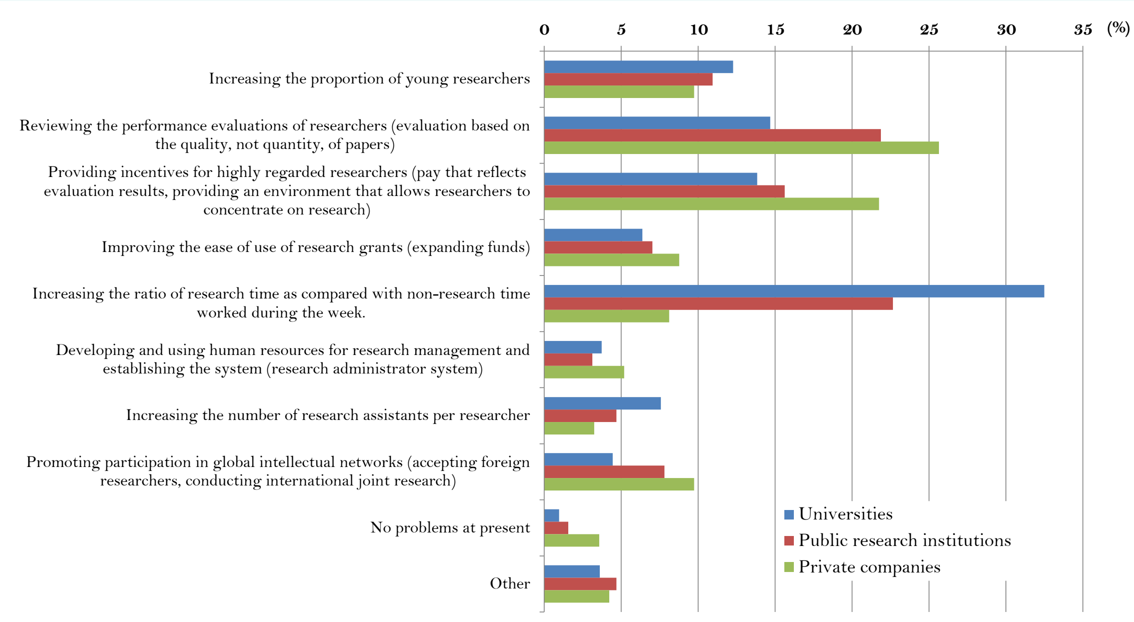
4) Suggestions for revitalization of R&D and researchers' awareness

So far, we have shown that research activities in Japan have been losing vital power—Japan's increasing rate of internationally co-authored papers is smaller than that of other developed countries; Japan's activities in research areas attracting international attention are fewer than those of other countries; and the number of projects involving high-risk research are decreasing in Japan even though the importance of high-risk research is increasing.

Various organizations have discussed the direction of measures regarding these concerns. For example, the Council for Science and Technology Policy (CSTP) made a suggestion as to the enhancement of basic research in its report "About the System Reform for Promotion of Science, Technology and Innovation—renovating the environment for creating innovation" (Expert Panel on STI Policy Promotion in December 2012). This suggestion was based on the following understanding: "the research infrastructure at universities must be strengthened by promoting a concrete system of reforms within universities—in terms of making the organizations open to recovering the basic strength of academia; in terms of responding to the globalization of research organizations; in terms of reforming organizations to provide young researchers with more opportunities; and in terms of promoting competition among universities in order to strengthen research bases." The suggestion then mentioned the following reforms: "strengthening research infrastructure at universities," "securing young researchers and improving research support systems," and "reforming competitive funds such as Grants-in-Aid for scientific research (KAKENHI)."

CST also formulated the "Basic Policy to Drastically Strengthen R&D Capacity in Japan" in April 2013, and planned to work out concrete measures regarding the response to international brain circulation, the promotion high-novelty and high-risk research, the establishment of a new evaluation system, and the development of research environments in which researchers can devote themselves in their studies . According to another survey of researchers about the situation of S&T[1], when asked what measures should be taken in order to strengthen the basic research capabilities of universities, the researchers working at universities emphasized securing more time for research, reviewing the performance evaluations of researchers (evaluation based on the quality, not quantity, of research papers), providing incentives for highly regarded researchers, and increasing the number of young researchers. Researchers working at private companies, however, emphasized reviewing performance evaluations and providing incentives for highly regarded researchers (Figure 1-2-9). There were also opinions suggesting that the number of research assistants should be increased and that the ease of use for research grants should be improved.

Figure 1-2-9 / Measures to be Taken so as to Prioritize the Strengthening of the Basic Research Capabilities of Universities (Percentage of the First Position)



Notes: 1. Respondents were shown the world rankings for each country's number of top 10% highly cited papers and were asked what measures should be taken in order to increase the top 10% papers from Japan in the future.

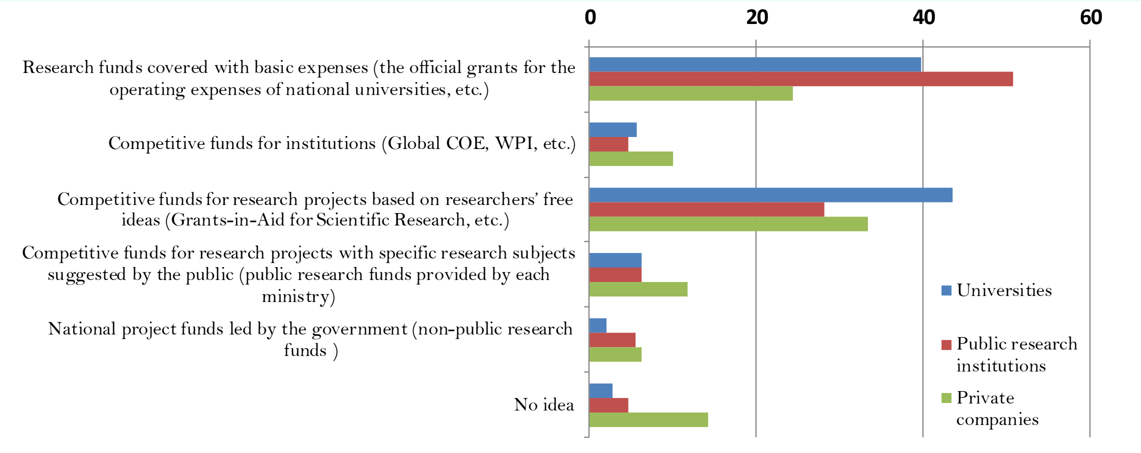
2. The question was asked of groups at universities and public research institutions (about 1000 people) and experts who have comprehensive view on innovation (about 500 people).

Source: NISTEP, "Analytical Report for 2012 NISTEP Expert Survey on Japanese S&T and Innovation System" (April 2013)

[1] NISTEP, "Analytical Report for 2012 NISTEP Expert Survey on Japanese S&T and Innovation System" (April 2013)"

As for the R&D funds that are necessary for enhancement of the research capabilities of universities, many researchers wanted the expansion of basic expenses and competitive funds for curiosity driven research projects (Figure 1-2-10).

Figure 1-2-10 / R&D Funds that Need to be Expanded in Order to Strengthen the Basic Research Capabilities of Universities (Percentage of the First Position)



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Source: NISTEP, "Analytical Report for 2012 NISTEP Expert Survey on Japanese S&T and Innovation System" (April 2013)

Based on these suggestions for the vitalization of research activities, we have summarized measures to be taken on the four following issues: 1) the improvement of the quantity and quality of research papers, 2) the vitalization of R&D activities in emerging areas and multidisciplinary areas, 3) the promotion of high-risk research, and 4) the introduction of a new evaluation method. There are also two other issues: the development of research environments to product quality research results and the establishment of international research networks that will lead to the production of internationally co-authored papers. These issues will be discussed in Subsection 2 of this section, "The Environment Suitable for Creative, Original R&D to Achieve Innovation" and in Subsection 3, "Establishing International Research Networks," respectively.

(2) Measures to improve the quality of research activities and to vitalize R&D activities

1) Aiming at improvement of the quantity and quality of research papers

First, we focus on the quantity of research papers. In Part 1, Chapter 1, 2 (1), we have examined the quantity of research produced in Japan and noted how they have been decreasing when compared with other countries. Here, we compare the situations of several countries by focusing on the relationship between the trend of R&D expenditure and the output of papers (Table 1-2-11). The fact that 70 percent of all research papers in Japan are produced at universities shows that universities play a key role in producing research papers. Thus, we pay attention to R&D expenditure in the university sector. Here, we compare the changes of those in major countries between 2000 and 2009, which can be obtained as the final data during this period.

Table 1-2-11 / Increasing Rate of R&D expenditures in the University Sector (Natural Sciences, Humanities and Social Sciences) and that of Research Papers Produced in all Sectors (Natural Sciences) in Major Countries from 2000 to 2009

Country	Increasing rate of R&D expenditures in the university sector from 2000 to 2009 (research expenses in 2009)		Increasing rate of research papers from 2000 to 2009 (Number of papers produced in 2009)	
Japan	5%	(2.2 trillion yen)	5%	(77,459)
U.S.	43%	(6.4 trillion yen)	27%	(306,805)
U.K.	56%	(1.3 trillion yen)	19%	(83,957)
Germany	33%	(1.7 trillion yen)	26%	(84,748)
France	28%	(1.1 trillion yen)	27%	(62,888)
China	335%	(1.5 trillion yen)	312%	(124,052)
Korea	115%	(0.6 trillion yen)	171%	(37,532)

Notes: 1. Since the definition of the university sector varies from country to country, international comparisons should be made carefully.
2. R&D expenditures include the expenditures incurred in the natural sciences, humanities and social sciences (natural sciences only in Korea in 2000). The value for Japan is corrected and estimated by the OECD (R&D D expenditures in the university sector with the full-time equivalent of personnel expenses).
3. Each currency is converted into yen by the OECD purchasing power parity conversion.
4. Research papers are counted based on Thomson Reuters' Web of Science (natural sciences). All of the sectors included (university sector and others)
5. The number of papers in 2009 is the average for the three years from 2008 to 2010.
6. When a paper is coauthored in multiple countries, the paper is counted as one in each country (the whole count method).
7. Source of each value:
<U.S.> NSF, "Science and Engineering Indicators 2012"
<Germany> "Bundesbericht Forschung und Innovation 2010"
<U.K.> National Statistics website: www.statistics.gov.uk
<Japan, France, Korea> OECD, "Main Science and Technology indicators 2011/2"
<China> The Ministry of Science and Technology, "Science and Technology Indicators of China"

Source: Created by MEXT based on NISTEP, "Science and Technology Indicators 2012" (August 2012) and "Benchmarking Scientific Research 2012" (March 2013)

The data shows that R&D expenditures have increased by 30 to 50 percent and that the number of papers has increased by 20 to 30 percent in Western countries. In Korea and China, both the R&D expenditures and the number of papers have doubled to be quadrupled. In these circumstances, the increasing rates of Japan's indicators are both about five percent, which is smaller by one or more digits than that of other countries. One of the reasons why the increasing rate of Japan's paper production is lower than that of other countries is that the increasing rate of Japan's R&D expenditure has remained low when compared with other countries.

On the other hand, in order to improve the quality of research papers, it is important to pay attention to the facts that many internationally co-authored papers are of high quality and that many high quality papers have been produced in inter-/multidisciplinary research areas. Conducting research in inter-/multidisciplinary areas and drawing international attention means going through grinding competition. This naturally leads to an improvement in the quality of papers, and consequently, the citation rate is expected to rise. Strategic measures suitable for the characteristics of each research area are also needed in order to promote the production of internationally co-authored papers.

It is important for Japan to show the world that Japan is developing research activities that have the highest level of S&T in the world. Excellent research activities produce highly cited research papers, and papers that are highly cited are regarded as high-quality papers. It is thus important to set goals for increasing the number of the top 10% highly cited papers and the top 1% highly cited papers, and to strengthen the research activities of high quality in order to meet these goals and in order to produce a larger number of excellent papers.

2) Vitalization of R&D activities in emerging/multidisciplinary research areas

For emerging, multidisciplinary research areas, measures to utilize competitive funds, which are the main research funds for researchers belonging to universities, have been started in an effort to vitalize R&D activities.

The Strategic Basic Research Programs (creation of new technological seeds) conducted by the Japan Science and Technology Agency are implemented by competitive funding intended to create original technical seeds that lead to innovation. This program emphasizes the good judgment of a program director (PD), who supervises the operation of the entire project, and the program officer (PO), who is in charge of practical business such as the examination of research subjects. With strategic objectives established in a top-down style, the program promotes creative research. Based on the “Programs to Accelerate the Revitalization of Japan” (Cabinet decision on November 30, 2012), the system has been operated since FY 2012 in order to fully conduct a quality examination and the selection of research subjects without depending on a performance-based system or a council system and to carry out a system reform that allows the flexible use of funds and time for research on PD’s initiative.

On the other hand, Grants-in-Aid for Scientific Research (hereinafter referred to as “Grants-in-Aid”) are major competitive funds in Japan and are used to support scientific research based on researchers’ imagination and creativity in all the research fields ranging from the humanities and social sciences to the natural sciences. Applications are screened through peer review by several experts whose specialized areas are close to those of the applicants. In FY 2012, about 26,000 excellent research subjects were selected from about 90,000 new applications. In order to support joint research conducted in collaboration with researchers from different research fields and in order to support research aiming to create emerging/multidisciplinary areas, the “Grants-in-Aid for Scientific Research on Innovative Areas” were established in FY 2008. Research projects funded by these grants will be conducted for five years and will be given between 10 and 300 million yen per year. In FY 2012, new projects were selected from among 21 different areas, and positive results are expected in the future.

The “List of Categories, Areas, Disciplines and Research Fields” (hereinafter referred to as the “List of Research Fields”), which was created to conduct the fair and efficient examination of Grants-in-Aid, has been improved by taking into account the trends of research at different times. When making an application, researchers are supposed to choose the area in which their application is to be examined from the List of Research Fields and according to the contents of their research plan. The List of Research

Fields in FY 2012 consisted of 298 items. Researchers who will apply for Grants-in-Aid for Scientific Research can choose the most suitable item for their research and take an examination. The allotment for each item is determined based on the requested research expenses and the number of research subjects that have been applied for.

However, some have suggested that the classification of the List of Research Fields and the examination methods should be further improved in order to promote emerging and multidisciplinary research areas. Starting with the applications for funding in FY 2013, the whole List of Research Fields was widely reviewed, and a new system was introduced so as to allow researchers to choose multiple items when applying for Grants-in-Aid for Young Scientists (B). These improvements are expected to further promote emerging/multidisciplinary research areas.

The review system of the National Science Foundation (NSF) is a useful reference when encouraging research projects in emerging/multidisciplinary research areas in spite of the difference in the system, its mechanisms and the scale of its budget and personnel. In NSF's system, many POs, and other reviewers suitable for reviewing the contents of an application, participate in the examination process, and the system requires time to conduct examinations in writing and for consultation.

We have looked at Table 1-2-5 and found that researchers' participation in those research areas drawing international attention, such as inter-/multidisciplinary areas, is insufficient in Japan. Thus, our challenges are to vigorously participate in these research areas, to secure diversity in research, and to increase the share of papers written in each area in order to improve the quality of research. It is also important for Japan to play a key role in creating new research areas. To this end, strategic measures are needed. However, since the knowledge that will become the source of innovation is often acquired unexpectedly, research based on researchers' imagination and creativity is also important. It is therefore essential for the government to emphasize research conducted based on researchers' imagination and creativity by using competitive funds and by simultaneously promoting strategic measures in each of the research areas drawing international attention.

Column 1-2

NSF's Review System

The National Science Foundation (NSF) is an independent institution of the U.S. government that promotes basic research and education in science and engineering. The annual budget for the NSF is about 7.0 billion dollars, of which about 6.7 billion dollars is allocated for basic research and education through competitive funds. The funds bear about 20 percent of the budget for basic research at all of the universities in the U.S.: about 80 percent for computer science and about 60 percent for biology (excluding the funds provided by the National Institutes of Health [NIH]), mathematics, social sciences and environmental science.

In FY 2011, approximately 52,000 applications were submitted for the competitive funds allocated to universities and other research institutions by the NSF[1]. About 500 program officers selected reviewers who were suitable to examine the contents of the applications by using the database of more than 390,000 researchers from around the world, and they performed the examination process.

The examination method varies with the characteristics of the proposed program: mail review (7% of all applications), panel review (62%), or both (28%). In some cases, a virtual panel using the Internet is held. For each panel review, 10 to 15 people are selected as reviewers or clerks. 10 to 20 applications are assigned to each reviewer and about 10 applications are assigned to each clerk. At least two reviewers and one clerk are assigned to one application. Reviewers need to produce a draft review of the applications assigned to them and then send them for a panel review. While holding a panel review, reviewers stay at the NSF for three days. Each reviewer has a personal computer, which displays a review draft and shares it among the reviewers, and they discuss each application. The reviewer who is in charge of the application then gives a presentation about it. Afterward, the reviewers discuss the presentation and a clerk records it. Every participant gives their opinions and sometimes revises the review draft on the computer, and they work together to complete a review paper. Lastly, the reviewer in charge of the application sums up the discussion and the panel decides whether the application should be selected. Applications will be ranked if the program officer directs the panel to do so. These processes are advanced with the program officer's agreement. Based on the results of the serious discussion, the program officer works out a fund allocation plan after the panel review.

These creative processes enable applications to be examined by the best qualified reviewers throughout the entire processes, even if the applications belong to new, multidisciplinary research areas.

Nearly half of the program officers at NSF are temporarily transferred from universities (many of them are professors or associate professors [tenured]) and the job is a requirement of their career path. After serving as a program officer, they then return to their universities and sometimes expand the frontiers of scientific research or disseminate funding, which, helps their carrier progression.

3) Measures to promote high-risk research

One of the efforts that offer suggestions for the promotion of high-risk research is the measure to support "transformative research," which has been started in the U.S. NSF defines transformative research as follows: transformative research involves ideas, discoveries, or tools that radically change our understanding of an important existing scientific or engineering concept or educational practice or that leads to the creation of a new paradigm or field of science, engineering, or education. The National Science Board (NSB), a policy-making body of NSF, advised NSF in May 2007 to ensure that all parties understand the policy so as to promote the selection of transformative research projects in all of the existing programs. In November 2011, NSF invited applications for CREATIVE[2], which is a pilot program of an NSF integrated program (INSPIRE[3]) for the promotion of new interdisciplinary research and education and which particularly emphasizes transformative research in interdisciplinary research

1 Report to the National Science Board on the National Science Foundation's Merit Review Process, Fiscal Year 2011 (This is a summary of NSF's activities between October 2010 and September 2011, made public in May 2012. The following data was quoted from the report.)
2 Creative Research Awards for Transformative Interdisciplinary Ventures
3 Integrated NSF Support Promoting Interdisciplinary Research and Education

areas. Since applications must be research projects in interdisciplinary areas, prior agreements by POs in two or more sections are required, but those are just for the preliminary examinations. The main selection is performed by an internal examination only, and the selected projects are granted up to one million dollars for a period lasting up to five years.

Key factors that could change scientific values or that could create economic and social values often exist in applications of high-risk research that has no prospect of producing results or that denies conventional ideas. NSF's attempt is a policy in which the government takes a risk to promote high-risk research, and it also utilizes a bottom-up method, which is the key to securing a diversity of research.

There are, however, other efforts that are in the more practical stages of application than NSF's transformative research. For example, in 2007 the U.S. Department of Energy (DOE) established ARPA-E[1], a department specializing in high-risk research, in order to support the development of innovative energy technology and systems. In 2012, The U.S. National Institutes of Health (NIH) conducted R&D to bridge the gap among the results of basic research and drug discovery and therapeutic methods, and has been working on high-risk research by establishing the National Center for Advancing Translational Science (NCATS) aiming at the quick commercialization of research results.

In addition, the U.S. Defense Advanced Research Projects Agency (DARPA) has carried out high-risk research and has made remarkable achievements. DARPA was founded in 1958 as the Advanced Research Projects Agency (ARPA), an organization that supervised research to divert the most advanced S&T to military technology in a short period of time, but then it was reorganized in 1972. Now, its missions are to avoid "technological surprises" that threaten national security by maintaining the technological superiority of the U.S. Forces and to support research that is expected to bridge the gap between basic research and military research and to bring great innovative rewards. The FY 2012 budget for DARPA was 2.8 billion dollars.

DARPA (or its predecessor, ARPA) has particularly drawn attention because of its excellent research results, such as ARPANET, the prototype of the Internet, and GPS, the Global Positioning System. For example, ARPANET was first developed in 1969 as a network connecting four personal computers, and today it is used worldwide as the Internet, which has an immeasurable impact on society, economics, and methods of communication. In addition, DARPA had studied a positioning system using satellites since the 1970s, and the research results have shown society convenient ways of using the function for specifying positional information. Consequently, private companies have come to develop many new products by applying the technology over a wide range, including its use in car navigation systems, cellphones, logistics management, fish detection and biological research on wild animals.

In Japan, the Grants-in-Aid for supporting scientific research includes the Grants-in-Aid for Challenging Exploratory Research, which supports research with high, challenging objectives in its infancy. The government has made the grant a foundation since FY 2011, so as to allow research funds to be used over multiple years. The government also has raised the selection rate of new research subjects from 10% to about 30% in order to strengthen support for high-risk research.

Strategic Basic Research Programs (creation of new technological seeds), a funding program of JST, have been promoting basic research aiming to overcome the crucial challenges Japan has been facing. The

1 Advanced Research Projects Agency-Energy

project collects research proposals based on the strategic objectives established by the government. Its goal is to create original technological seeds that will grow into S&T innovation and thus reform society and the economy. One of the characteristics of the project is that the program officers who perform examinations and administration duties have responsibilities and discretion. They select research proposals that are expected to lead to innovation even if they are challenging, high-risk subjects that would not be selected in a performance-based system or a in a council system. So far, the research proposal submitted by Shinya Yamanaka, M.D., Ph.D., a professor at Kyoto University has been selected by a PO's and supported. In this way, the program supported the creation of human iPS cells[1], which led to his winning the Nobel Prize for Physiology or Medicine in 2012. In addition, the quality control function and activities of the PD council, which makes plans for the operation policy of the entire project and for system reforms, have been strengthened so that quality examinations and selections can be performed across the projects, regardless of research area.

Considering the situation of overseas activities that actively involve work on high-risk research to produce results, MEXT will start the Center of Innovation Science and Technology based Radical Innovation and Entrepreneurship Program (COI STREAM) in FY 2013. In this program, first, a vision is created by thinking about what needs will have arisen 10 years now, and by considering the viewpoint of a changing people or a changing the society. Then, in order to give shape to the R&D plan, the backcasting[2] method is used to derive a R&D theme that carries a high risk, but which will have a great impact on society and the economy if it is realized. When the program is implemented, a project leader is elected from industrial circles, and a researcher at a university becomes a research leader; thus, the industry and universities properly share their roles and conduct R&D in close cooperation. The government also takes risks in the early stages of R&D and helps create innovation, sometimes collaborating with venture businesses.

In this way, efforts to promote high-risk research have already started in some of the programs in Japan as well. Such programs should be carried out steadily in the future.

As mentioned above, DARPA developed GPS as a technology that would meet future needs, and the technology has spread to the private sector (spin-off[3]) and is now widely used. This is an example where a high-risk research subject that would otherwise be difficult for a university or a private company to conduct was carried out to meet the government's needs and, yet, the research produced excellent results which led to innovation.

In Japan, a joint technology for H-II rockets was improved by a private corporation and was developed into a seismic isolation system using laminated rubber bearings. In the future, it is thus necessary to actively work on high-risk research and to further facilitate activities that promote spin-off of the results.

4) Introduction of new evaluation methods

Evaluation systems should be built appropriately in order to encourage researchers and research institutions to perform excellent activities. It is also necessary to reflect the results of evaluation in their

1 Induced pluripotent stem cells
2 While "frontcast" defines solvable problems by thinking from the perspective of the seeds in an individual area of S&T, backcasting is a method of specifying necessary R&D subjects or technological seeds by thinking from the perspective of social needs or other challenges and then visualizing and analyzing them
3 In contrast, diverting advanced civil technology to military technology is called spin-on.

treatment. The Science Council of Japan (SCJ) issued a report entitled "How the Research Evaluation System should be in Japan—Shifting to evaluation systems that nurture and support researchers (Committee for Reviewing "Research Evaluation Systems" for SCJ in October 2012). According to a questionnaire given to the members mentioned in this report, more than half of the respondents said that they did not think that research evaluation functioned effectively enough to find creative research projects, or to quickly disseminate the research results to the general public and society, or to create new/interdisciplinary research areas. Based on these circumstances, the "Basic Guidelines to Drastically Strengthen R&D Capacity in Japan" which was adopted by the Council for Science and Technology (CST) in April 2013 mentioned new evaluation systems, in addition to other promotion measures, as current issues.

In order to further vitalize R&D and to effectively connect its results to the creation of S&T-based innovation and to solutions for social and economic issues, it is necessary to promote the following: evaluation that is helpful in improving the quality of research papers, evaluation that encourages international research activities, and evaluation that contributes to the promotion of new, inter-/multidisciplinary research and to high-risk research. It is also necessary to perform R&D evaluation not only from the viewpoint of the creation of knowledge, such as the number of published papers and citation impact, but also from the viewpoint of social and economic outcomes and impacts.

In the United States, the National Science Foundation (NSF) bears approximately 20% of the support offered by the federal government for basic research conducted at colleges and universities. NSF reviews all of the proposed projects related to NSF research funds in the "merit review system". In order to advance the "peer review system" which is an assessment and verification process conducted by experts in the same research field, NSF has introduced two merit review criteria since 1997: "Intellectual Merit" that leads to intellectual development and "Broader Impact" that leads to education and the improvement of social benefits. As for the "Broader Impact," it had been pointed out that there were challenges with what was actually stated in the application documents and how those challenges were handled during the review process. Although the NSF implemented revised merit review criteria, i.e. the Intellectual Merit and Broader Impact remain unchanged.

In the United Kingdom, the Research Councils, which fund for research projects in all the disciplines at universities and research institutions, basically conducts assessments by peer reviews by peer review. These days, when applying for research funding and submitting proposals, applicants are required to state not only the "Academic Beneficiaries," but also "Impact Summaries" and "Pathways to Impact," including the economic and social impacts. Through the assessment system, researchers are expected to think about the excellent scientific, economic and social impacts that their research activities will have and how to realize them; it also encourages them to actively engage in the process (Figure 1-2-12).

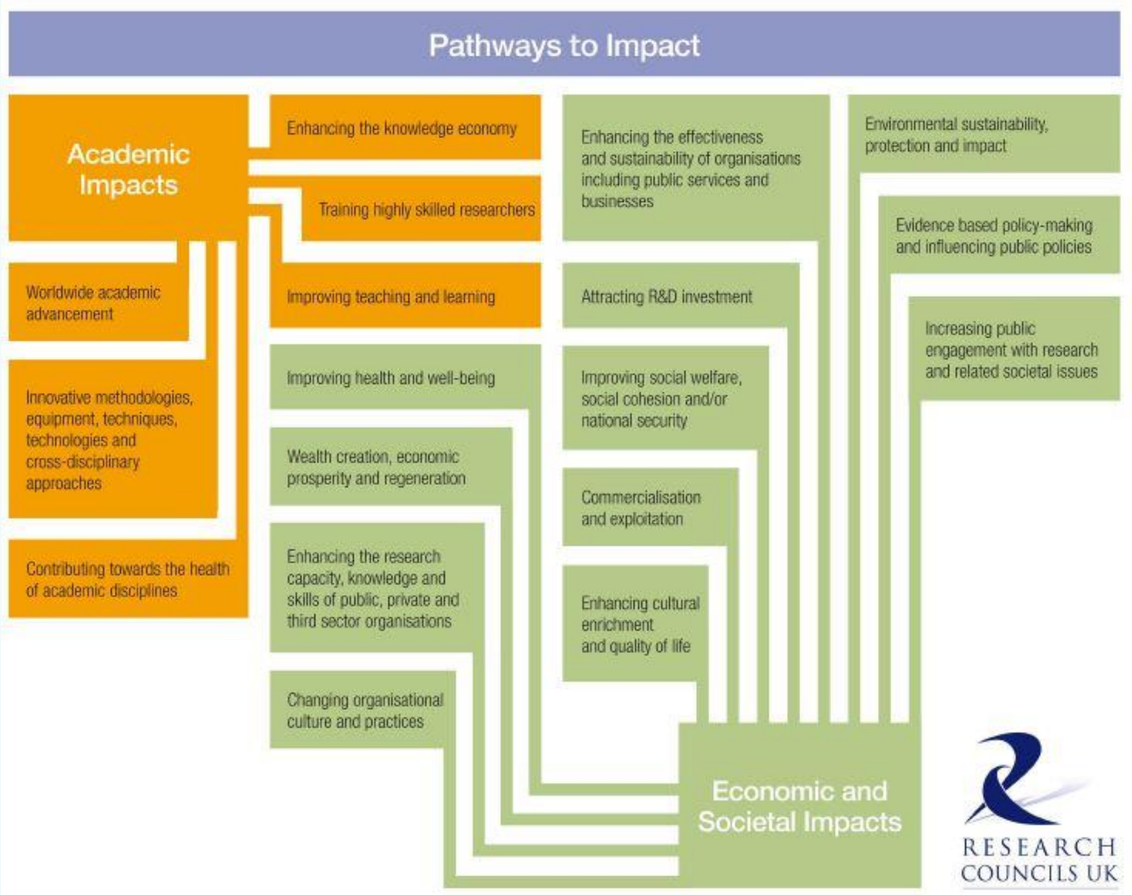
The Higher Education Funding Councils had conducted the Research Assessment Exercises (RAE), which assessed the quality of research in higher educational institutions across all research disciplines. The RAE results were used to allocate research funds to each institution. The RAE is replaced by a new assessment system called the Research Excellence Framework (REF). In the REF to be completed in 2014, a new assessment criterion, called as Impact (the impact of research beyond academia) will be introduced in addition to Outputs (the quality of research outputs) and Environment (the research environment).

In this globally severe socioeconomic situation and financial conditions, researchers in North American and European countries are required to consider what scientific, economic and social benefits their research activities will produce as a result of funding. Measures that require reviewers to positively assess from the economic and social viewpoints have also been promoted. In Japan, when reviewing and assessing applications for research funds or when evaluating R&D institutions, researchers or R&D policies, we should not attach too much importance to the expected scientific benefits or the objective numerical indicators on research papers, such as the number of published papers or their citation impact, which are the outputs and outcomes of activities in the past. It is important to actively introduce new R&D evaluation systems that allow for accurate review and evaluation in light of the scientific economic and social benefits according to the purposes and objectives of each policy, project or institution.

Since there is no international standard for the methods of measuring the economic and social impacts of R&D activities, both public institutions, such as funding agencies, governmental departments and international organizations, and the community of researchers are expected to voluntarily work on methods for measuring the impacts of R&D.

Taking into account these situations and issues of R&D in Japan as well as global trends, the Council for Science and Technology worked out the General Direction of the Revision of the "Guidelines for Evaluation of Research and Development in MEXT" in April 2013 (Figure 1-2-13). In this way, R&D evaluation system has been reformed and these reforms should further contribute to the creation of S&T –based innovation, to the improvement of the quality of research papers, and to the promotion of high-risk research.

Figure1-2-12 / Research Councils UK “Pathways to Impact”



Source: Research Councils UK

Figure 1-2-13 / General Direction of the Revision of the "Guideline for Evaluation of Research and Development in MEXT"

General Direction of the Revision of the "Guideline for Evaluation of Research and Development in MEXT"

Council for Science and Technology (CST)
April 22, 2013

1. Perception of the current situation and challenges on the revision of the guidelines

(a) In order to revitalize the economy and to strengthen international competitiveness, it is essential to strongly promote the realization of innovation on the basis of S&T.
(b) It is important to promote basic research and scientific research that contribute to the progress of S&T and that will be the source of creation for S&T-based innovation. It is necessary to effectively produce research results by promoting basic research while also pressing for the re-systemization of existing theories based on the most advanced S&T knowledge.
(c) In order to respond to the challenges of S&T that were revealed by the Great East Japan Earthquake, it is necessary for researchers to correctly understand the demands of society and to reform R&D systems so that they will be able to solve these challenges by bringing together a variety of expertise.
(d) It is widely recognized throughout the world that it is necessary for the scientific community to consider the significance and state of their R&D activities and to show their willingness to improve, act and explain them, while also taking into account the actual circumstances in which they must carry out R&D by using limited, valuable natural and financial resources, given this severe socio-economic situation and financial condition.
(e) It is necessary to precisely conduct evaluations based on purpose, to build a system in that the results of evaluations are effectively reflected, for example, by the means of proper follow-up, and to avoid the harmful effects caused by an increase in frequency and burdens of evaluations.

⇒ Considering these various challenges regarding R&D in Japan (as well as the current trends, socio-economic situations, and world affairs), the government, funding agencies, universities, R&D institutes, researchers, and reviewers should be well coordinated and conduct R&D evaluations based on the items below. They should also examine the effects as to whether or not the results of evaluations have led to vitalization of the following R&D activities.

2. Creating S&T-based innovation; and promoting a system to solve the issues

(a) Do not stop at the stage of intellectual inquiry, but promote all the stages of R&D leading to its applications in society, including practical application of the results, so as to meet societal needs.
(b) Note that the number of published papers and citation impact are objective indicators, but do not rely on these values alone and for the sake of establishing easy goals. Instead, develop other objective indicators that complement them.
(c) Grasp the cost-effectiveness of R&D activities correctly; for example, evaluate them all by using the point-addition system and reflect upon the results of the evaluations in order to change treatments and allocations of funds. In addition, take necessary measures, such as considering the introduction of new indicators regarding the quality and novelty of research and their impact on the progress of science.
(d) In light of the enhancement of R&D platform, it is necessary to promote R&D in collaboration with R&D organizations such as venture businesses that do not have sufficient track record but have technological capabilities and a passionate interest in the practical application of R&D.
(e) Researchers who work at R&D institutions shall perform R&D to achieve the missions of their organizations.

3. Promoting high-risk research, inter-, multi- and trans-disciplinary research with strong impact

(a) High-risk research carries a high risk of failing to achieve the goals of R&D. However, there are R&D results that have a strong social, economic or scientific impact if it is successful. In order to actively promote high-risk research, inter-, multi- and trans-disciplinary research, it is necessary to prepare methods and criteria systems of assessment and ex-post evaluation, based on the purposes of the policy measure, program and system. (The system to allow the project leader to have discretion and responsibilities is also important.)

(b) When conducting assessment, check to see if the R&D results may have a strong impact on technological or other challenges and whether or not the project leader has the management capability to successfully carry out the R&D.
(c) In the R&D implementation stage of high-risk research, properly review the target and the plan on a timely basis, including its discontinuation, while considering the progress of the R&D and changes in circumstances. If a challenging R&D project has an unexpected but significant ripple effect after failing to achieve the initial target, the project should be rated as a meaningful experience. The evaluation criteria that allow such judgment should be established.
(d) Clarify the fair treatment of inter-, multi- and trans-disciplinary research in the process of examination of the R&D programs that are not intended to create new research areas. In this way, pick out promising research in its infancy and revise the evaluation criteria and evaluation methods properly, according to the progress of the research.

4. Promoting nurture and support for junior researchers who will lead the coming generation

(a) Promote measures that encourage junior researchers and allow them to show their creativity.
(b) Promote measures that fairly treat postdocs and doctoral students, create a good research environment, and support junior researchers so that they can become independent and move to a variety of career paths.
(c) Taking into account the situation where junior researchers' profiles, such as careers, ages and nationalities, have diversified, prevent them from unfairly suffering disadvantages.
(d) Promote the diversification of women's career paths and improve research environments to foster female researchers who are engaged in R&D.

5. Preventing evaluation from becoming formalistic and losing substance, relieving the increased burdens of evaluation

(a) Evaluation should be conducted by reviewers who are well informed of the purpose and elements of evaluation; self-evaluation is particularly fundamental and important. It is necessary to reconstruct evaluation systems that are founded on quality self-evaluation and based on high ethical standards. Independent evaluation and external evaluation based on self-evaluation should be rationalized and simplified.
(b) In some cases, where exactly the responsibility or authority lies has become unclear as a result of the introduction and systematization of evaluation. Thus, evaluation should be used to allow the decision-making entity to make good judgments. The evaluation system should be reconstructed from this point of view.
(c) Research is classified in many ways: basic research, applied research, developmental research; academic research, strategic research (innovation-oriented research, etc.), commissioned research (problem-solving research, etc.); individual research, organizational research, interorganizational joint research, research that involves society as a whole, and international joint research. Taking into account the position and method of each type of research and the characteristics of research institutions, it is necessary to optimize the allocation of funds and assessment methods in order to maximize the results.
(d) Train personnel having expertise in evaluation and personnel capable of designing evaluation system. Improve the capability of personnel engaged in evaluation and promote career development.
(e) Give PD (PO) responsibilities and authority. Clarify and strengthen them. Make the evaluation system rational and flexible.

6. R&D program evaluation

(a) If a specific goal can be established to achieve a policy for the creation of S&T-based innovation, it is expected to implement the "R&D program evaluation", introduced on a full scale for the first time, through setting time scale with a level of program and evaluating the achievement of objectives effectively.
(b) When introducing the R&D program evaluation, make the evaluation consistent with existing evaluation systems (policy evaluation, university evaluation, evaluation of independent administrative institutions, competitive funding system, etc.). Proceed by trial and error and step by step in a rational and effective way.
(c) As for basic research and academic research, it is necessary to carefully avoid the expectation of results from a uniform and short-term perspective. Give their characteristics full consideration in the R&D program evaluation.

2 The Environment Suitable for Creative, Original R&D to Achieve Innovation

Developing an environment suitable for R&D is an essential factor in vitalizing S&T activities in order to achieve innovation. In this paragraph, we analyze the present situation of the general research environment in Japan (as described in Chapter 1) in more detail and point out the challenges of making Japan "the world's most innovation-friendly country." Lastly, we summarize ongoing programs and their future direction.

(1) Challenges for research environments in Japan

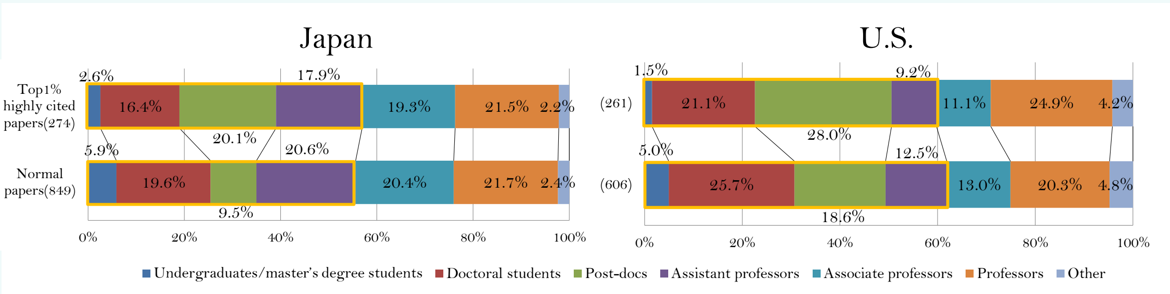
1) Research environments surrounding young researchers

Japan has taken various measures to enhance the creativity of young researchers since the first Basic Plan. It is, however, necessary to further strengthen these measures.

In the U.S. research papers whose first author is a young researcher, such as a doctoral student, postdoc, lecturer or assistant professor, account for approximately 60% of the papers produced at universities (Figure 1-2-14). The percentage of young researchers among all authors is approximately 40%, which shows the crucial role of young researchers in research activities. Postdocs, in particular, account for 28% of the first authors of the top 1% highly cited papers which attracts great attention.

First authors of many papers produced in Japan are also young researchers, but when compared to the U.S., the percentage of papers whose first author is a young researcher is small both in normal papers and top 1% highly cited papers. In addition, the percentage of assistant professors is higher in Japan than in the U.S.

Figure 1-2-14 / Academic/professional Positions of the First author of Papers Produced at Universities (Natural Science).



Note: The results covered papers whose authors were listed by the degree of authors' contribution to the focal paper.

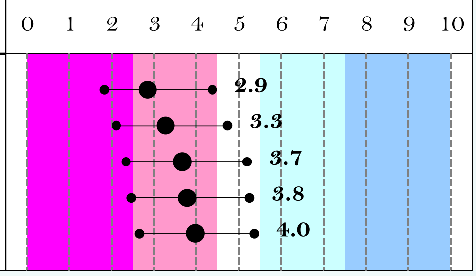
Source: NISTEP, the Institute of Innovation Research of Hitotsubashi University and the Georgia Institute of Technology, "Knowledge creation process in science: Basic findings from a large-scale survey of researchers in Japan and the U.S." (December 2011)

Leading Japanese researchers and experts were asked about the situation of S&T in Japan during the period of the third Basic Plan in a questionnaire (Figure 1-2-15). According to the results, they answered that the situation has been getting better regarding the environment to provide young researchers at universities with independence and opportunities. This is indicated by the fact that the index increased by more than 1 point from 2006, when the third Basic Plan started. When asked about the reasons why they raised the rating, respondents mentioned the introduction of a start-up fund in Grants-in-Aid

(Grant-in-Aid for Research Activity Start-up), the introduction of the Tenure Track System based on the "Promotion of Environmental Improvement to Enhance Young Researchers' Independence," and the "Funding Program for Next Generation World-Leading Researchers." On the other hand, the average of the index was still in the insufficient levels, i.e., 4.0, indicating that the respondents thought the measures should be continued in the future.

Figure 1-2-15 / Improvement of the Environment to Provide Young Researchers with Independence and Opportunities

Question		Insufficient ← Index → Sufficient (0–10)
Do you think the improvement of the environment to provide young researchers at universities and public research institutions with independence and opportunities is sufficient? (Universities) (Examples of improvement: introduction of the Tenure Track System, expansion of competitive funds for young researchers, provisions for start-up expenses for newly selected research, improvement of research-supporting systems and securing space for research)	FY 2006	2.9
	FY 2007	3.3
	FY 2008	3.7
	FY 2009	3.8
	FY 2010	4.0



Note: The index takes on values from 0 (insufficient) to 10 (sufficient). If the index is 3 or 4, it means improvement is still insufficient. If it exceeds 5, there are few problems. 6 and 7 indicate a fairly good status.

Source: Created by MEXT based on NISTEP, "Analytical Report for 2010 Expert Survey on Japanese S&T System and S&T Activities by Fields" (May 2011)

As described in Chapter 1, the research environments for young researchers in Japan are unstable; they are not permitted to conduct research independently and their career paths are unclear. In light of this situation, it is necessary to develop environments that allow excellent young researchers to focus on their research independently without anxiety about their future. CST's "What the Science and Technology Policies should be in the Future in View of the Great East Japan Earthquake (suggestion) (January 2013)" also pointed out the need for systematic efforts to establish a variety of career paths of young researchers. The unclear career path of postdocs, who are researchers in the making, is a serious problem when viewed from the perspective of the development of Japanese researchers.

2) How to treat researchers

Next, we pay attention to the treatment of researchers. In the 2012 NISTEP Expert Survey on Japanese S&T and Innovation System, there was a question about the provision of incentives for researchers based on the results of performance evaluation. The answers of university respondents indicated "a strong recognition of insufficiency" on the whole.

SCJ pointed out in its report: "How the Research Evaluation System should be in Japan—switching to an evaluation system that trains and supports researchers" on October 24, 2012. It pointed out, as an issue for examination, the need to design Japan's research evaluation system in such a way that ensures that the evaluation results will be linked to the incentives for researchers and research institutions and that will lead to an improvement of research activities and policies.

Wage structures in Japan are generally based on a seniority system, and researchers at universities are no exception. The national universities in Japan were reorganized as corporations in 2004, and each corporation has discretion and responsibilities as to its employment of faculty and staff, and personnel cost control. As a result, in some cases, an annual-salary system separated from the payroll is used. It is important to further promote the introduction of a wage system in which excellent performance is clearly reward. For example, given a fair and effective evaluation system, researchers with remarkable performance should be properly rewarded and may be selected as leaders of a research team, while those with poor performance should be treated as such.

As for their treatment at universities in other countries, according to a survey conducted by the American Association of University Professors, the average annual income of university professors in the U.S. in 2012 was $212,300 at Columbia University, the highest amount; $207,300 at Stanford University; and $203,600 at the University of Chicago[1]. These universities are highly ranked on various lists. Under the global brain circulating situation, it is important to switch to a system (in terms of wage, etc.) that allows research institutions in Japan to participate in the international competition for talented personnel.

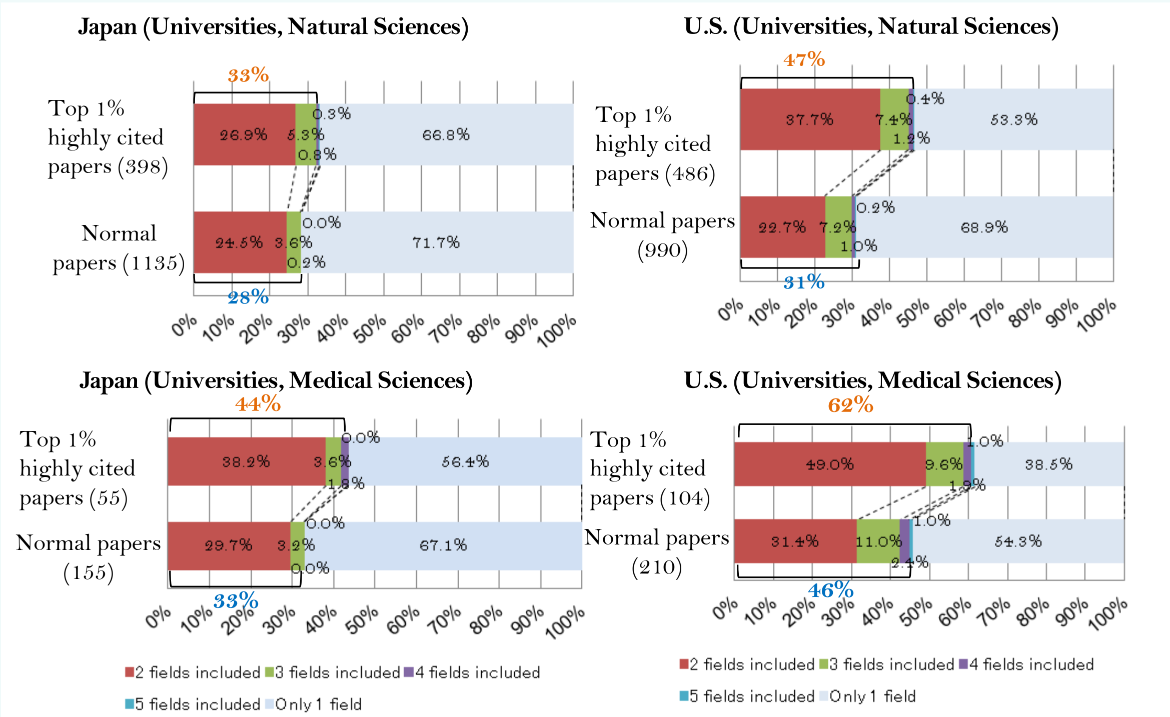
3) Cross-disciplinary exchanges

According to Science Map 2008, mentioned in Part 1, Chapter 2, Section 1, (1), 2), many of the research areas attracting international attention had close linkage with other research areas. The map thus indicates that the integration and fusion of knowledge have been taking place among these research areas. The report also revealed that in the late 1990s there were many combinations between the life science fields in interdisciplinary/multidisciplinary areas, but today combinations between a life-science field and a non-life-science field have increased and spread on Science Map.

The effect of interdisciplinary integration can be seen in the composition of authors of research papers. For example, in the natural sciences, in Japan, 33% of the top 1% highly cited papers were produced by research teams consisting of researchers in multiple disciplines, while only 28% of all papers were produced by such teams. This indicates that research papers drawing more attention tend to have a higher diversity of expertise on the research team. In addition, when Japan was compared with the U.S., the top 1% highly cited papers produced in the U.S. had a higher diversity of expertise on the research team than that in Japan (Figure 1-2-16). For this reason, increasing the diversity of expertise on a research team is significant, and promoting cross-disciplinary exchanges is needed.

1 They are allowed, for example, to receive a salary of nine months and, during the remaining three months, conduct research and other activities while receiving a salary from external funds.

Figure 1-2-16 / The Comparisons of Diversity of Expertise on a Research Team between Japan and U.S.

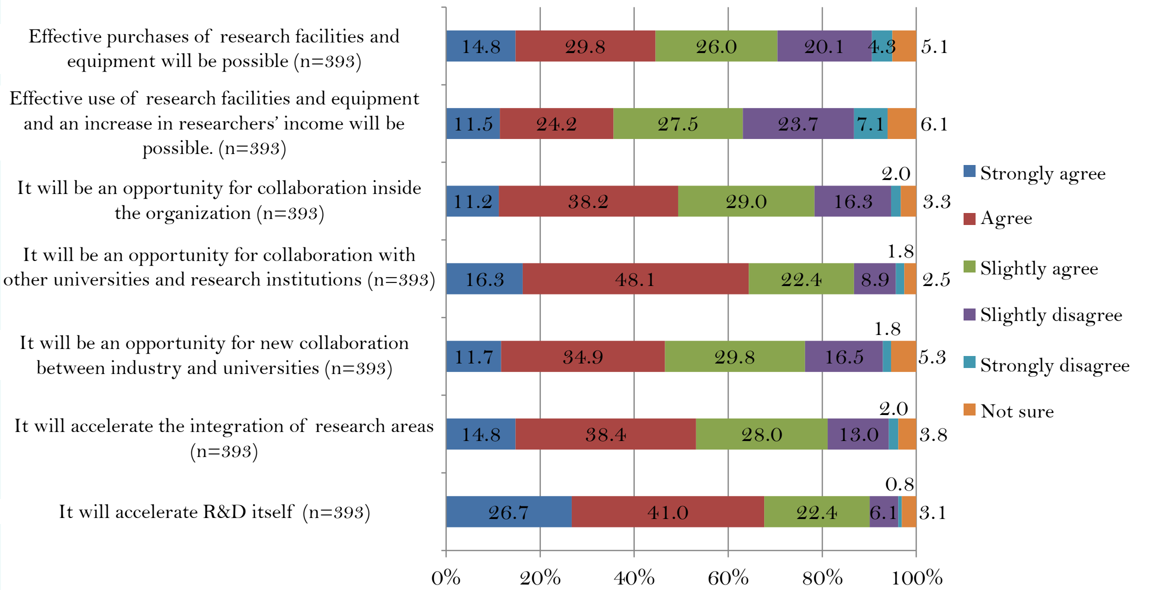


Source: NISTEP, the Institute of Innovation Research of Hitotsubashi University and the Georgia Institute of Technology, "Knowledge creation process in science : Key comparative finding from the Hitotsubashi-NISTEP-Georgia Tech scientists' survey in Japan and the U.S." (December 2011)

Shared use of research facilities and equipment is one of the measures used to promote cross-disciplinary exchanges. Cross-disciplinary exchanges will be advanced through collaborative research conducted by researchers in different disciplines and organization sharing research facilities and equipment. The Council for Science and Technology (CST) suggested (January 2013) "the need to establish a system (R&D platform) to effectively advance measures, such as the shared use of research facilities and equipment, the promotion of sophisticated equipment, the promotion of the effective use of shared facilities and equipment in R&D projects, and the promotion of coordination between research facilities and equipment."

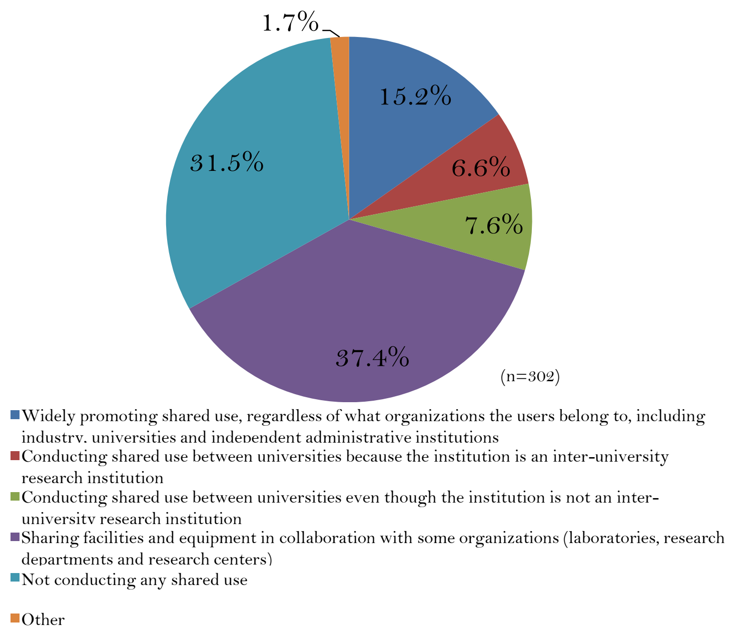
The effect of cross-disciplinary exchanges through the shared use of research facilities and equipment has already been recognized. According to a survey conducted by the National Institute of Science and Technology Policy, the question "Will the promotion of the shared use of research facilities and equipment accelerate the integration of research areas?" was answered with more than 80 percent of the respondents recognizing its effect and answering that they "Strongly agree," "Agree," or "Slightly agree" (Figure 1-2-17). Thus, the promotion of the effective use of research facilities and equipment by sharing them is desired.

Figure 1-2-17 / The Effects Promoting the Sharing of Research Facilities and Equipment



Note: The respondents were professors and their equals belonging to universities and the like.
Source: NISTEP "Proposal on Shared University Research Facilities and Equipment - Status of the Usage of Research Facilities and Equipment by University Researchers outside their Affiliated Laboratories - " (August 2012)

Figure 1-2-18 / Ways of Sharing by Researchers Who Manage or Take Care of Research Facilities and Equipment at University Laboratories



Source: NISTEP "Proposal on Shared University Research Facilities and Equipment - Status of the Usage of Research Facilities and Equipment by University Researchers outside their Affiliated Laboratories - " (August 2012)

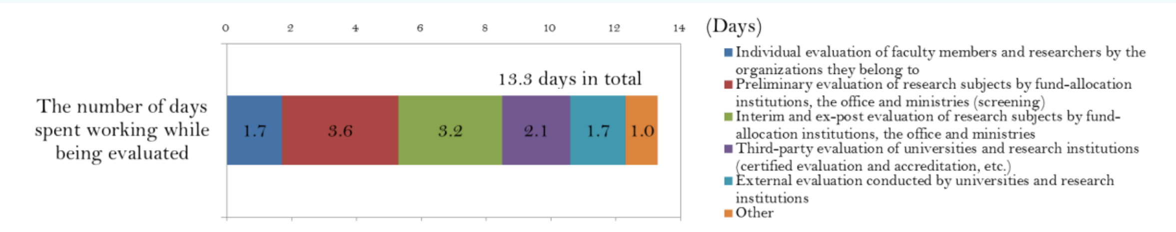
However, in this survey, only about one third of the researchers who managed or took care of research facilities and equipment answered that they practiced shared use with organizations other than the organization to which they belonged. This answer indicates that shared use across organizations has not developed well (Figure 1-2-18). Accelerating the shared use of research facilities and equipment is the key to the promotion of cross-disciplinary exchanges in the future.

4) Shortage of research assistants

We have examined a reduction in the time faculty members can spend for research in Figure 1-1-38. The services, which researchers have to perform in addition to their research activities, have been diversified in recent years. According to the 2012 NISTEP Expert Survey on Japanese S&T and Innovation System, university researchers' services (excluding research) that have increased recently include services regarding university administration, office work regarding the evaluation and application for competitive funds, work related to compliance (such as safety control of chemicals and control of equipment and software), maintenance of research facilities and equipment, preparing entrance examinations and other work for examinations, management of academic societies and study groups, and dealing with students' private lives. The office work regarding competitive funds has been increasing because it involves project management, including funds management, and office work about intellectual property.

SCJ pointed out that the burdens of research evaluation have increased as it has become a system. According to a survey of its members, they spent an average of 13.3 days a year working on evaluation as an organization or an individual, or as the one being evaluated when applying for competitive funds[1] (Figure 1-2-19). Although evaluation is a necessary part of work, it should be effectively performed.

Figure 1-2-19 / The Number of Days Spent for Evaluation in a Year as an evaluatee



Source: Created by MEXT based on SCJ's suggestion, "How the Research Evaluation System Should be in Japan—switching to an evaluation system that trains and supports researchers" (October 2012)

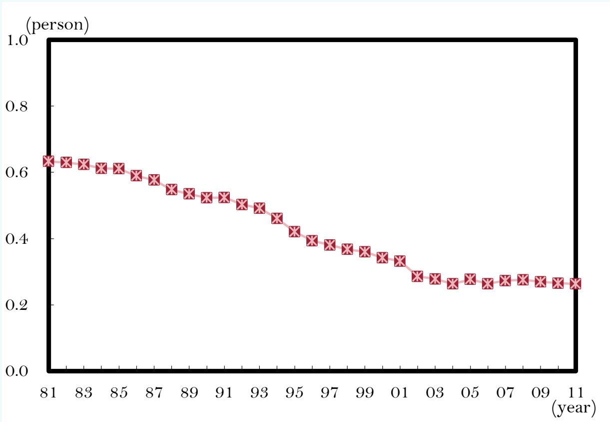
CST's Working Group on the Revision of MEXT R&D Evaluation Policy of the Working Party on R&D Evaluation of the Subdivision on R&D Planning and Evaluation summarized the main points of these issues by stating, "Harmful effects have been taking place due to an increase in the frequency and burden of various kinds of evaluation: the policy evaluation based on the Government Policy Evaluations Act(2001), the evaluation of independent administrative institutions based on the Act on Independent

1　SCJ, which conducted the survey, and the Board for Reviewing the State of Evaluation System said: "This data is about a specific sample, the members of SCJ and it never represent all the researchers in Japan."

Administrative Agency (2001), the evaluation of national university corporations based on the National University Corporation Act (2003), and university accreditation (2004)." The group pointed out, "It is necessary to review what a rational and effective R&D evaluation should be."

In this way, researchers' duties have been diversified in recent years. There were some comments asking for an increase of research assistants to deal with the diversified duties in the 2012 NISTEP Expert Survey on Japanese S&T and Innovation System, mentioned above. Nonetheless, the number of research assistants per researcher in Japan tended to decrease and it has remained on the same level for the past 10 years (Figure 1-2-20). In addition, the number of research assistants per researcher in Japan is smaller than that of other major countries (Figure 1-2-21).

Figure 1-2-20 / Trend Line of the Number of Research Assistants per a Researcher

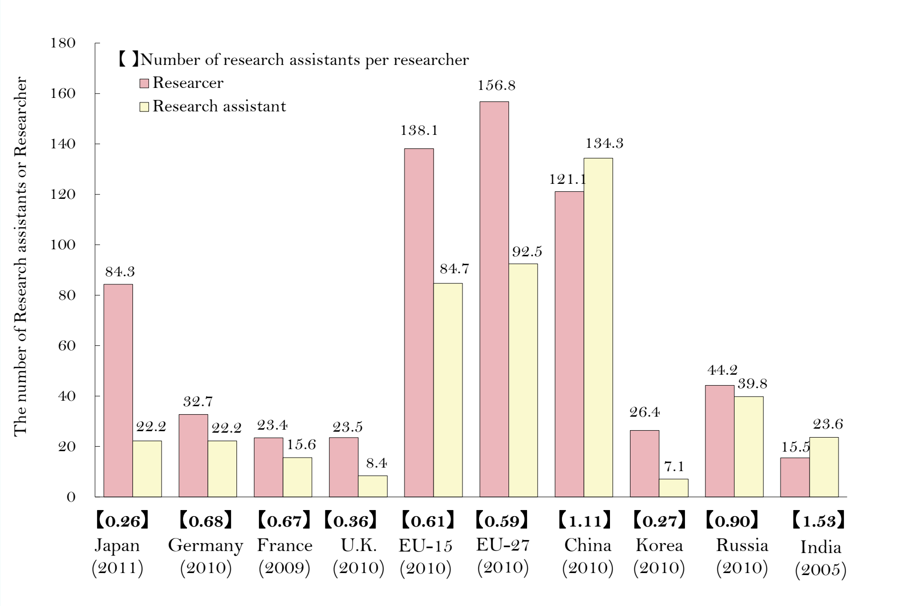


Notes: 1. The number of researchers and assistants are included that of human and social sciences, and the number is that as of 31st, March of each year (before 2000, as of 1st April).

2. Created by MEXT based on Statistics Bureau, Ministry of Internal Affairs and Communications 'Report on the Survey of Research and Development'

Source: MEXT "Indicators of Science and Technology (FY 2012)"

Figure 1-2-21 / The Number of Research Assistants per a Researcher in Major Countries



Notes: 1. The number of research assistants per researcher was done a trial calculation by MEXT based on the headcount of researcher and research assistants.
2. The number of researchers in human and social sciences are included for every country.
3. "Research assistant" means a person who assist researcher, provide technical service or an administrative staff. In the case of Japan "Research assistants" include research assistants, technical staff, administrative staff for research and persons concerned.
4. The figures for Germany are estimated.
5. The figures for U.K. are provisional.
6. The figures for EU are calculated from provisional figures and estimated figures by OECD.
7. The figures for India are estimated.
8. Japan :Statistics Bureau, Ministry of Internal Affairs and Communications 'Report on the Survey of Research and Development'
India :'UNESCO Institute for Statistics S&T database' , others: OECD "Main Science and Technology Indicators Vol. 2012/1"

Source: MEXT "Indicators of Science and Technology (FY 2012)"

So far, we have analyzed the situation of S&T in Japan, as described in Chapter 1, in view of research environments. The results have revealed the following needs:

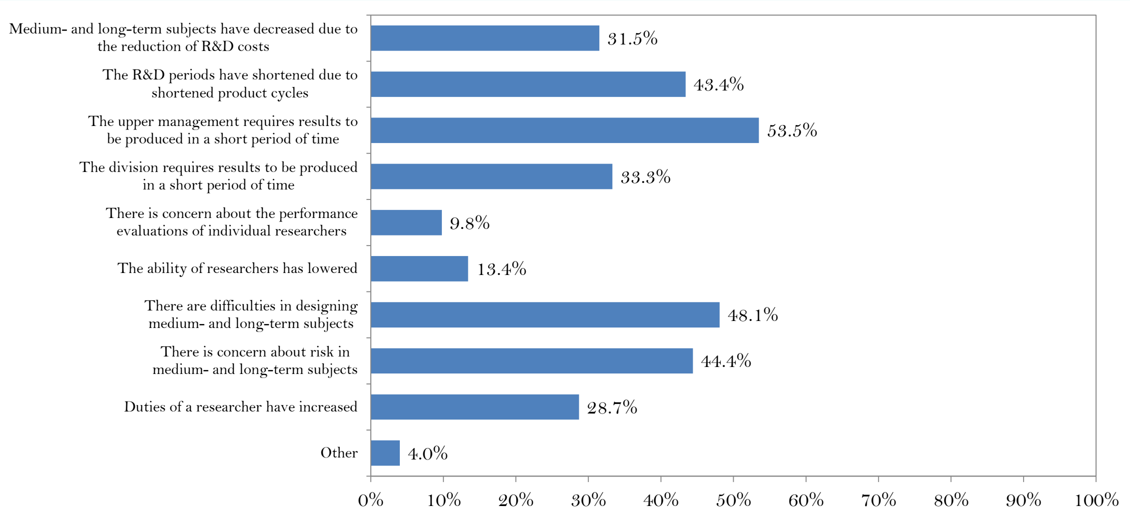
· Research environments that allow young researchers to become independent
· Treatment based on ability
· Integration and exchanges among different research fields and organizations
· Research environments that allow researchers to concentrate on research

(2) Challenges in creating innovation based on S&T

1) Challenges to research activities at companies

As shown in Figure 1-1-21, R&D expenditure has been decreasing at companies. In addition, research subjects that require results to be produced in one to four years have increased while research subjects that take more than five years of the R&D period have been decreasing (refer to Figure 1-1-22). As for the reasons for the shortened period, the following answers ranked highest: "The upper management requires results to be produced in a short period of time," "Difficulties in designing medium- and long-term subjects," and "Concern about a risk in medium- and long-term subjects" (Figure 1-2-22).

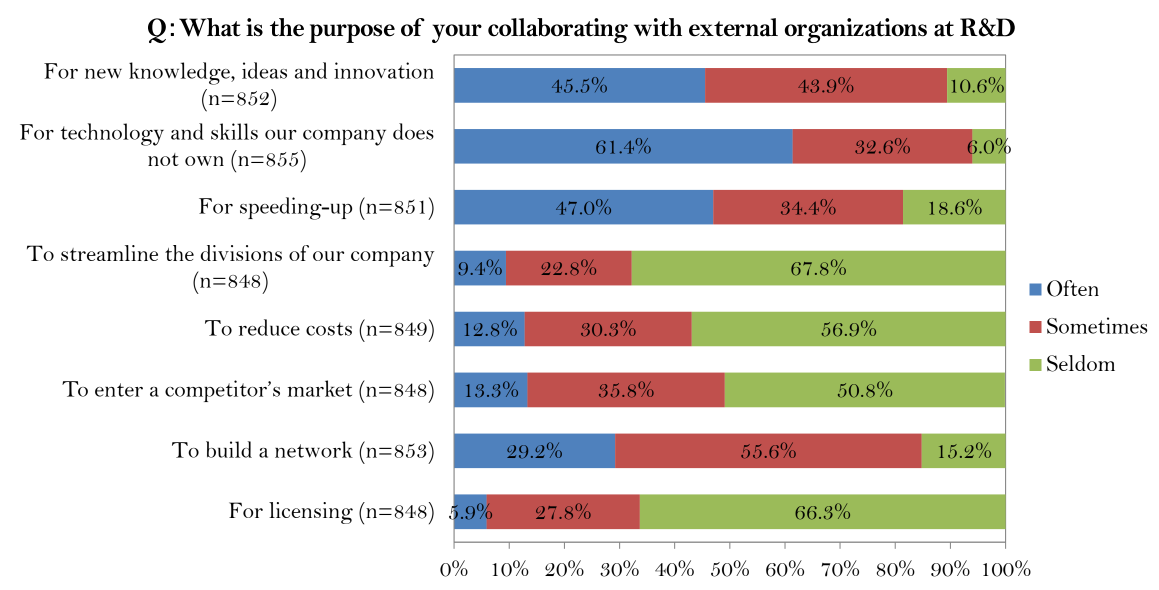
Figure 1-2-22 / The Reasons the Research Periods Have Shortened at Companies



Source: Created by MEXT based on METI "2011 Industry and Technology Research—research on medium- and long-term R&D at Japanese companies that contribute to the creation of innovation" (February 2012)

These answers reflect growing international competition and indicate that, because companies in Japan are required to refrain from investing in R&D and must yield steady results in a short period of time, they tend to avoid high-risk R&D that takes a long time to complete. Under the circumstances, companies have been promoting collaboration with external organizations, as shown in Figure 1-1-23. According to a survey report on companies related to R&D, entitled "Report of 2011 Industry and Technology Research—research on medium- and long-term R&Ds at Japanese companies that contribute to creation of innovation," almost half of the companies think, "The need for external collaboration has increased as compared with 20 years ago." When collaborating with external organizations, they expect technology and skills their company does not own; new knowledge, ideas and innovation; acceleration of research; and building a network (Figure 1-2-23).

Figure 1-2-23 / Purposes of Companies' Collaborating with External Organizations



Source: Created by MEXT based on METI "2010 Industry and Technology Research—research on the quantitative evaluation of open innovation regarding R&D investment efficiency at Japanese companies" (February 2011)

In this way, with limited funds, companies are promoting external collaboration in the hopes of acquiring technology and skills they do not own as well as acquiring new knowledge, ideas and innovation, which is shown by the increase in the external payment of research expenses (refer to Figure 1-1-23).

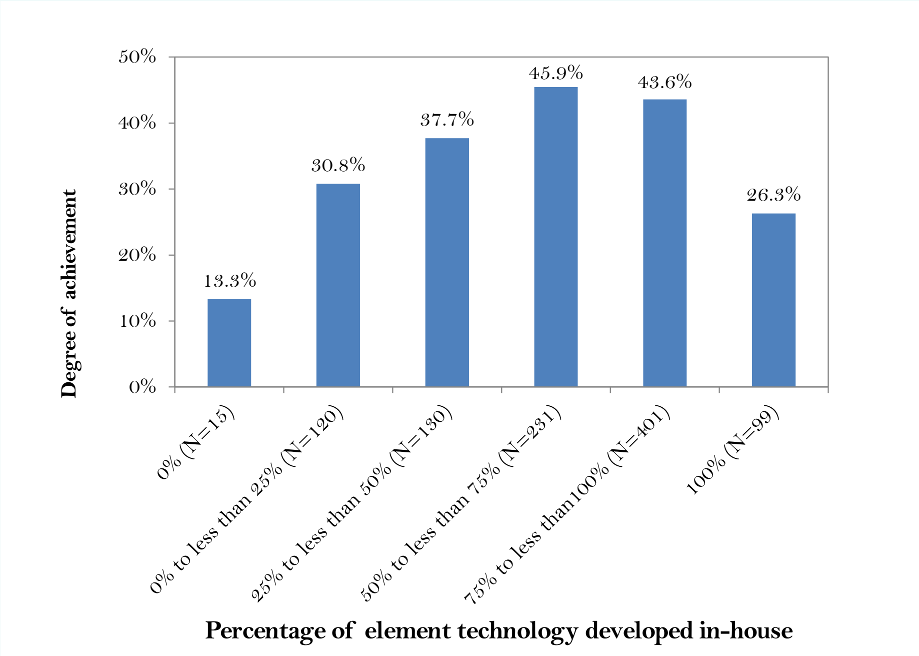
According to a survey conducted by the National Institute of Science and Technology Policy, only a small number of companies developed the entire elemental technology on their own to achieve radical innovation (release of a new product or a service with clear technological novelty or a new introduction of a new manufacturing method with technological novelty) (Figure 1-2-24). It shows that companies that have achieved innovation introduced a certain percentage of the element technology from the outside when developing that innovation. When taking a closer look, we see that 90.8% of the external payment of research expenses went to other companies. This shows their research collaboration with outside organizations was mainly not with universities but with other companies. However, more than half of the collaborations were between a parent company and a subsidiary; in other words, collaboration with other companies has not advanced far enough yet. According to a survey of companies[1], in regard to the "challenges to R&D collaboration with other companies in the same industry (horizontal collaboration)" they cited the handling of intellectual property and concerns that their company's technology and know-how may be exposed. Another survey[2] reported that "more than 75% of the companies carried out their research activities within the company or the company's group." The survey

1 METI "Report of 2011 Industry and Technology Research—research on medium- and long-term R&D at Japanese companies that contribute to the creation of innovation" (February 2012)

2 METI "2010 Industry and Technology Research—research on the quantitative evaluation of open innovation regarding R&D investment efficiency at Japanese companies" (February 2011)

indicates that many companies want to promote open innovation, but in fact they cannot because of the concern above.

Figure 1-2-24 / The Percentage of Technology Developed In-house and the Degree of Achievement Regarding Radical Innovation



Source: NISTEP "2011 Report of Survey on Research Activities of Private Corporations" (October 2012)

In this way, R&D at companies in Japan reflects the growing international competition, which has caused a reduction of research expenses and shortened the research periods. When they try to collaborate with other companies for financial efficiency, they encounter the matters of intellectual property rights, which make the collaboration between independent companies difficult.

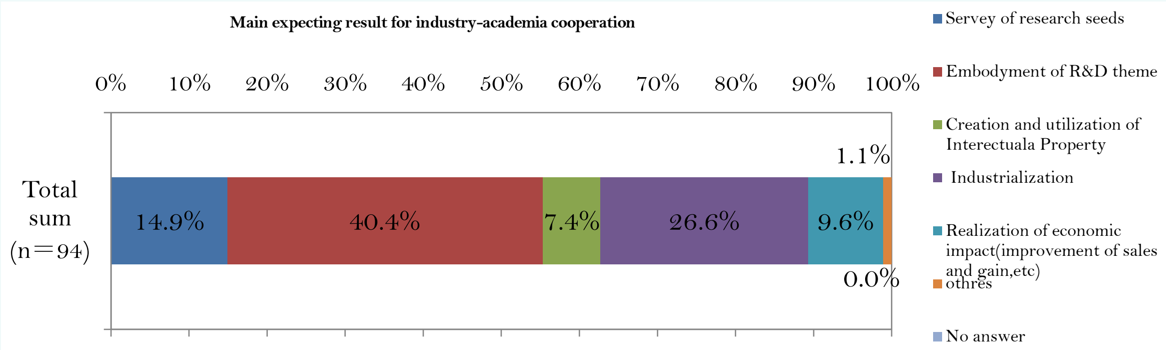
2) Challenges in using research results at universities in Japan

(Challenges to industry-academia-government cooperation research)

As for the purposes for cooperation with universities, companies cited "embodiment of the R&D theme" (the largest, at 40.4%) and "industrialization" (the second largest, at 26.6%) and a "survey of research seeds." Only about one fourth of them expected universities to focus on industrialization in addition to research (Figure 1-2-25). As described in Chapter 1, both the number of industry-university cooperation projects and the number of research funds that universities accepted from companies have increased, but the scale of research projects has remained small (refer to Figure 1-1-33, 34). According to another survey[1], expenses paid to universities and public research institutions accounted for only 2.5% of the external payment of companies' R&D expenditure. Such a small research project may contribute to the promotion of research to some extent, but it is not large enough for the creation of innovation with strong impact or industrialization.

1 NISTEP "2011 Report of Survey on Research Activities at Private Corporations" (October 2012)

Figure 1-2-25 / Main Expecting Result for Industry-Academia Cooperation



Source: Report on Investigative Research Projects On Evaluation of FY 2010 MEXT Policy (March 2011)

According to the 2012 NISTEP Expert Survey on Japanese S&T and Innovation System, regarding universities and public institutions' interest in the needs of private companies; university respondents rated its sufficiency level as 5.0 on a scale of 10 while private company respondents rated its sufficiency level at 3.6. About the amount of research information exchanges among industry, university and government and the amount of mutual intellectual stimulation, private company respondents rated it at 3.3, and the usage condition of intellectual property that private companies acquired from R&D conducted by universities and public research institutions was rated at 2.7. Private company respondents gave a lower rating to all items compared with university respondents (Table 1-2-26).

In other words, when promoting industry-academia-government cooperation, researchers at universities think they understand the needs of companies while companies think their understanding of the needs is not adequate enough—thus, there is a discrepancy in awareness. The survey also shows that respondents both in private companies and universities consider the amount of research information exchanges among industry, university and government and the amount of mutual intellectual stimulation to be insufficient. Both of them also think the private companies' use of research results produced at universities is insufficient.

In addition, to the question, "Do the results of basic research and other R&D in Japan satisfactorily lead to innovation?" both the private company and university respondents gave low ratings, of 3.0 and 3.8, respectively. Both of them also gave low ratings (in the 3 point range) to the question, "Is creative basic research sufficiently conducted as the source of future innovation?" These results indicate that they think creative basic research, which is the source of innovation, may have failed to yield results or, even if it has yielded results, that the results may have not led to innovation.

Table 1-2-26 / Attitude Survey on Industry-academia-government Cooperation

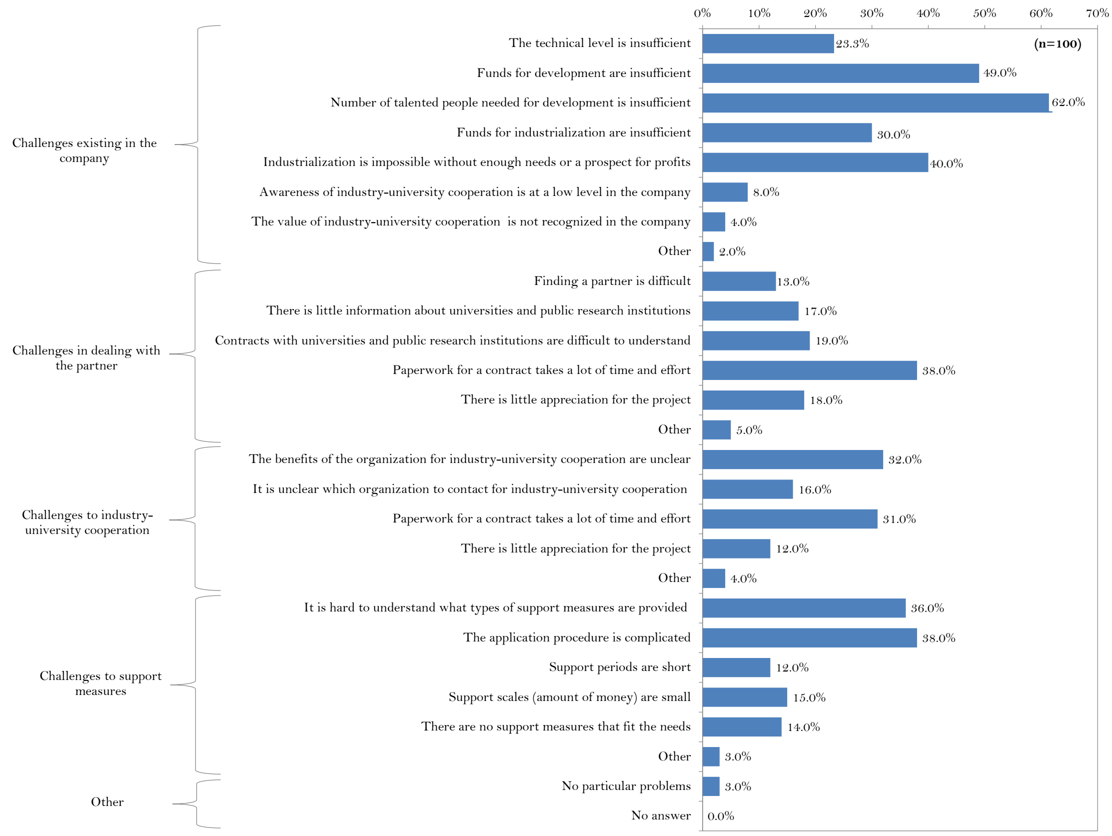
Questions	Universities	Public institutions	Private companies
Universities and public institutions' interests in the needs of private companies (technical challenges, etc.)	5.0	6.0	3.6
The amount of research information exchanges among industry, university and government and the amount of mutual intellectual stimulation	3.6	4.4	3.3
The usage condition of intellectual property private companies acquired from R&D conducted by universities and public research institutions	3.5	3.9	2.7
Do the results of basic research and other R&D in Japan satisfactorily lead to innovation?	3.8	4.0	3.0
Is creative basic research sufficiently conducted as the source of future innovation?	3.3	3.2	3.1

Note: Respondents choose the most appropriate rating from among the six ratings ranging from insufficient to sufficient (six-level rating) and then give it an index on a scale of 1-10.

Source: Created by MEXT based on NISTEP, "Analytical Report for 2012 NISTEP Expert Survey on Japanese S&T and Innovation System" (April 2013)

As for the challenges in utilizing industry-academia cooperation and the research results of universities, a survey by MEXT reported challenges existing in companies, such as a shortage of funds and talented personnel. Other than those, high on the list were challenges regarding communication and systems, indicated by comments such as "The benefits of the organization for industry-university cooperation are unclear," "What types of support measures are provided is hard to understand," "Paperwork for a contract takes a lot of time and effort," and "The application procedure is complicated" (Figure 1-2-27).

Figure 1-2-27 / Challenges in Utilizing Industry-academia Cooperation and the Research Results of Universities

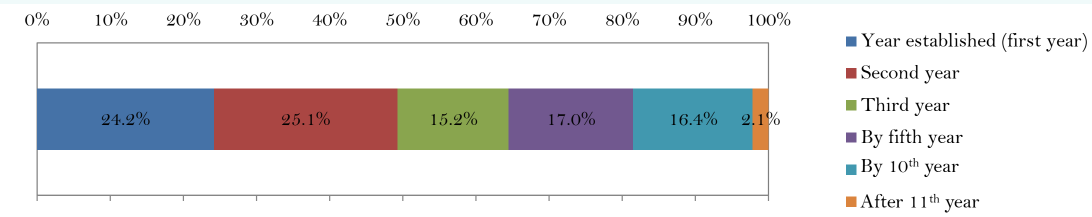


Source: Report on Investigative Research Projects On Evaluation of FY 2010 MEXT Policy (March 2011)

(Challenges of Academic Start-ups)

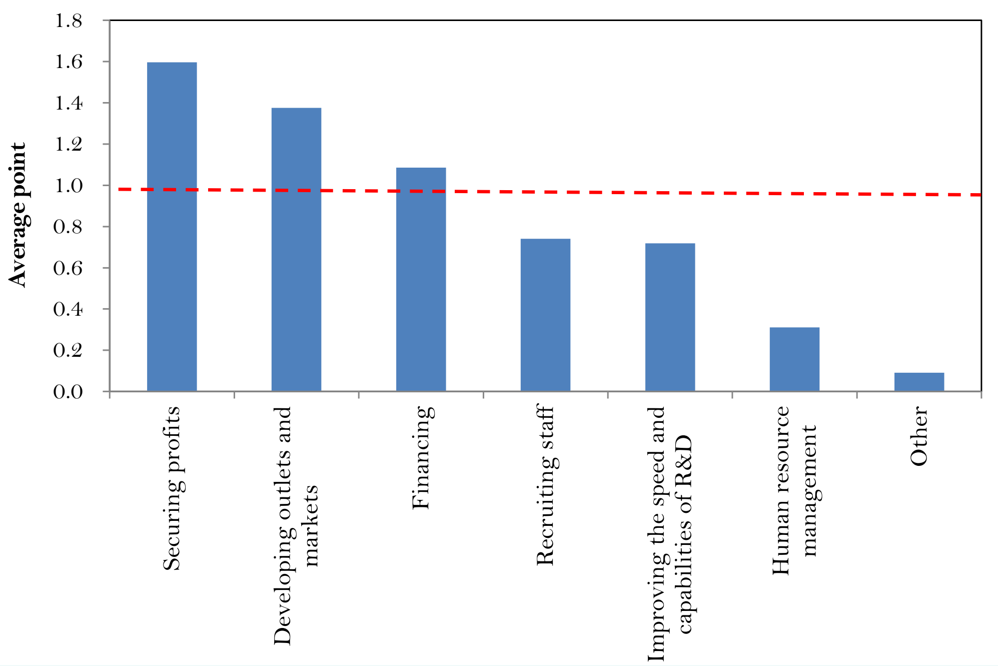
According to the NISTEP's "Academic Start-ups Survey," 50% of them indicated that it took them more than three years to get into the black (Figure 1-2-28). To the question, "What challenges do you feel now?" challenges regarding business, not technical ones, such as "securing profits" and "developing outlets and markets" ranked high (Figure 1-2-29). When considering academic start-up the result suggests that it is necessary to enhance not only the measures necessary to overcome technical challenges, but also the measures for commercialization.

Figure 1-2-28 / The Number of Years University Ventures Took to Go into the Black



Source: NISTEP "Academic Start-ups Survey 2011" (March 2012)

Figure 1-2-29 / What Challenges the University Ventures Feel Now



Note: Respondents were asked to choose the top three challenges they felt then. The first, second and third were given 3, 2 and 1, respectively, and the weighted averages were calculated.

Source: NISTEP "Academic Start-ups Survey 2011" (March 2012)

We summarize the challenges of creating innovation based on S&T as follows. First, we observe that companies, which should create innovation on their own initiative, have reduced the scales of research subjects and have shortened the periods of R&D due to a decrease in research expenses. Next, in the situation where conducting high-risk R&D is difficult, more and more companies are switching to measures to introduce external technology. However, many companies also hesitate to collaborate with other companies because of concern about the handling of intellectual property. In addition, collaboration between a parent company and its subsidiary account for more than half of the collaborations between companies. As for the industry-university-government collaboration meant to gain knowledge that companies do not have, they are not necessarily satisfied with it. On the basis of this situation, there will be a growing need for a system that allows companies to carry out high-risk research and for a system that provides consistent support for those universities promoting industry-academia-government collaboration until they industrialize their research results.