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Science Map 2010&2012

Study on Hot Research Area (2005 – 2010 and 2007- 2012) By Bibliometric Method

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Research Unit for Science and Technology Analysis and Indicators
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This highlight is English Translation of the following report

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Ayaka SAKA and Masatsura IGAMI, National Institute of Science and Technology Policy (NISTEP REPORT No. 159), July 2014

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1. OVERVIEW OF NISTEP'S SCIENCE MAP

The "Science Map" is a map that shows a snapshot of scientific research in the world. The National Institute of Science and Technology Policy (NISTEP) periodically created the map. Research areas receiving international attention (hot research areas) are quantitatively identified through an analysis of scientific paper database and their relative relationship are visualized.

The mapping of knowledge is a growing area of research, and a variety of studies are being conducted [Börner, Chen & Boyack, 2003 and references therein; Leydesdorff and Rafols, 2009]. The main feature of the NISTEP's Science Map is that its unit of analysis is a hot research area rather than focusing on traditional field classification, such as chemistry, physics, and materials science [Saka and Igami, 2007]. Research area level monitoring of scientific activities can provide policy makers and university administrators with more concrete information regarding the emergence of new concepts or viewpoints in science and about specific communities of researchers.

NISTEP's Science Map is created by the following three steps; (1) identification of research areas through the clustering of top 1% highly cited papers based on the co-citation analyses [Small and Sweeney, 1985a; Small et al., 1985b]; (2) visualization of research areas by mapping; and (3) extracting research area keyword based on the text-mining of titles and abstracts of papers.

To create Science Map 2012, approximately 70,000 of top 1% highly cited papers published in the six-year span from 2007 to 2012 were used. The top 1% papers were identified for each year and each of 21 ESI journal fields except for multidisciplinary field[1]. These top 1% highly cited papers were clustered to research areas by a two-step clustering (i.e., papers to research fronts, research fronts to research areas). Through this process, we obtained 823 research areas in Science Map 2012.

In this report, papers making up each research area (i.e., the top 1% papers) are called "core papers." Papers that cite core papers are called "citing papers." "Citing papers (top 10%)" refer to citing papers they are top 10% highly cited in the world as of the end of 2012. Core papers can be considered the papers that lead research areas. Exhibit 1 shows a conceptual view of a research area. If we consider a research area as a mountain, these core papers make up its summit. Citing papers could be thought as the foot of the mountain because they follow the core papers; accordingly,

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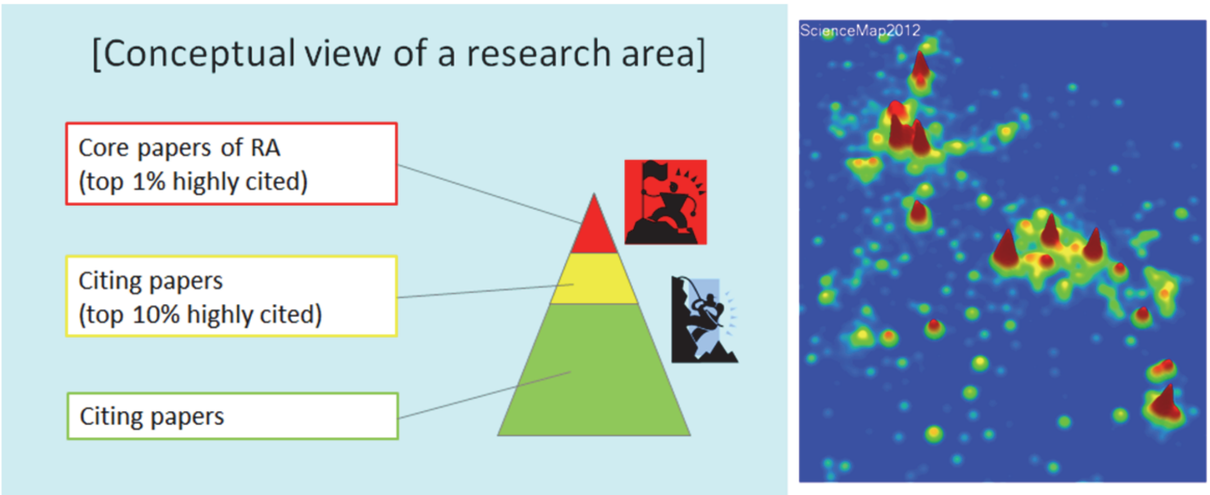
[1] *Papers published in multidisciplinary journals were reclassified into either of 21 ESI journal fields based on the information of backward citations.*

the citing papers (top 10%) can be thought as the broad middle portion of the mountain.

Exhibit 1 Conceptual view of a research area



In the past, we released Science Map 2002 (1997–2002), Science Map 2004 (1999–2004), Science Map 2006 (2001-2006), and Science Map 2008 (2003–2008). In addition, we have created Science Map 2010 (2005–2010) and Science Map 2012 (2007–2012).

In this highlights, we discuss the result of Science Map 2010 & 2012.

- Overview of current science and the status of Japan
  - The status of scientific research observed in Science Map 2012
  - Increasing ubiquity of inter-/multi-disciplinary research
  - International collaboration is getting a common mode of creation of high impact knowledge even in life sciences
  - Japan's falling share and diversity in the Science Map
- Categorization of research areas by using the Sci-GEO chart and understanding current activities of Japan
  - Current situation of Japanese S&T policy and reason why we created the Sci-GEO chart
  - Categorization of research areas by using the Sci-GEO chart
  - Trends in research activities in the world and benchmarking countries as seen with the Sci-GEO chart
  - Transition of Sci-GEO types over time
  - Analyzing characteristics of funding by using the Sci-GEO chart
- X-ray images of research activities at the institutional level on Science Map 2012

2. Overview of current science and the status of Japan

(1) The status of scientific research observed in Science Map 2012

In Science Map 2012 (2007–2012), 823 research areas receiving international attention (hot research areas) were identified; Exhibit 2 shows Science Map 2012. The Science Map provides a bird's eye view of the "mountains of scientific research" formed by core papers accumulated.

SCIENTIFIC RESEARCH CONTINUES TO EXPAND

823 research areas are identified as hot research areas in Science Map 2012. The number of research areas shows about 40% increase compared to that in Science Map 2002 (598 research areas), representing active knowledge creation, an increase in the number of papers being published, around the world.

TREND OF SCIENTIFIC RESEARCHES

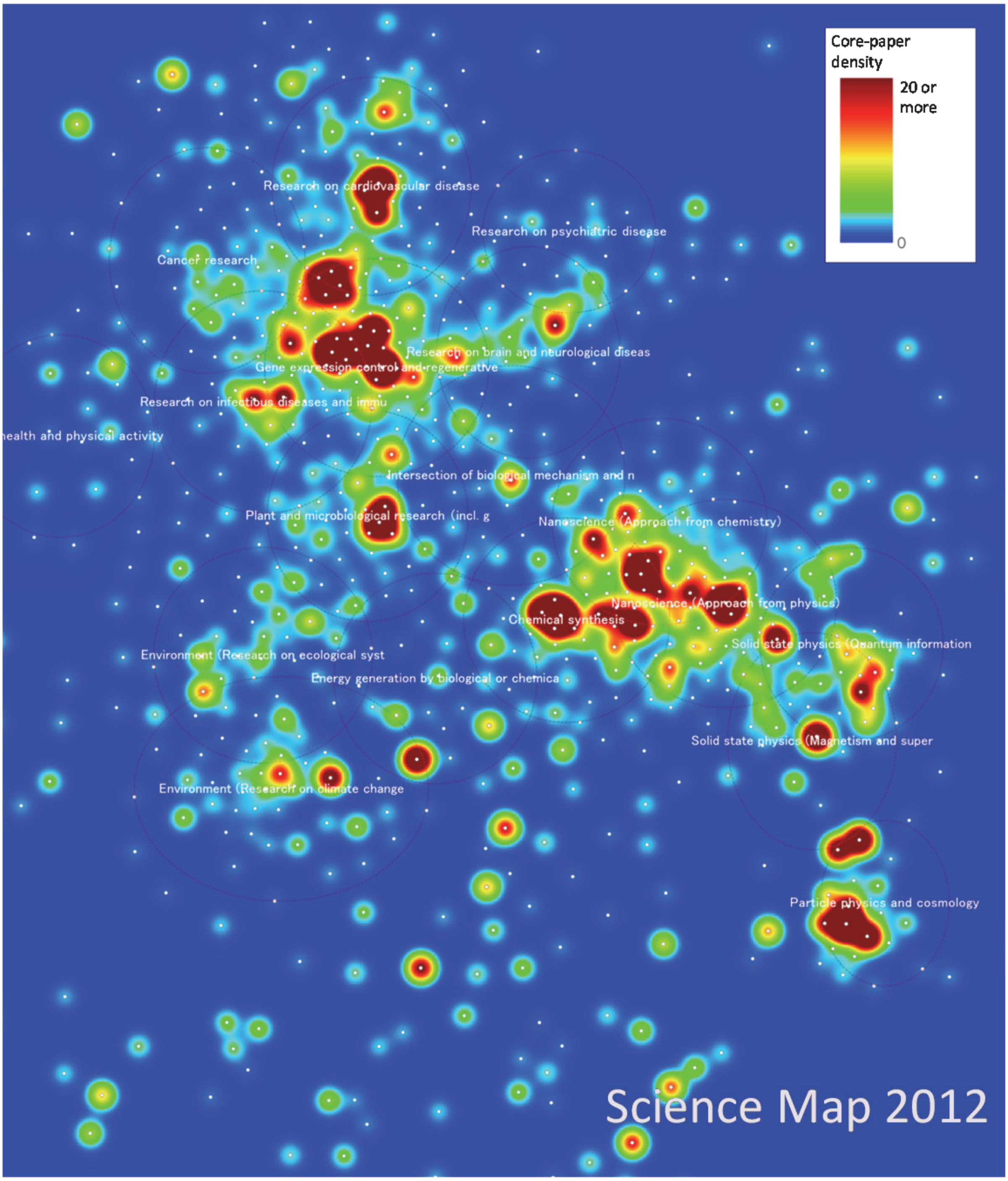
For Science Map 2012, we identified keywords that represent the characteristics of each of the 823 research areas based on the text-mining of titles and abstracts of papers. To make it easier to grasp the outline of Science Map, we developed a methodology to aggregate research areas sharing common keywords (research area groups) and depicted those groups on the map.

No.	Group of research areas	No.	Group of research areas
1	Cancer research	10	Environment (Research on climate change)
2	Research on cardiovascular disease	11	Intersection of biological mechanism and nano-scale phenomena (Life-nano bridge)
3	Public health and physical activity	12	Energy generation by biological or chemical approach
4	Research on infectious diseases and immunology (incl. gene expression control)	13	Chemical synthesis
5	Gene expression control and regenerative medicine	14	Nanoscience (Approach from chemistry)
6	Research on brain and neurological diseases	15	Nanoscience (Approach from physics)
7	Research on psychiatric disease	16	Solid state physics (Quantum information and optics)
8	Plant and microbiological research (incl. gene expression control)	17	Solid state physics (Magnetism and superconductivity)
9	Environment (Research on ecological system)	18	Particle physics and cosmology

(Note 1) Since the map is created by a force-directed placement method, relative location of research areas is important, there is an arbitrariness in the direction of X and Y axes. In this report, we present maps in which life sciences are located in the upper left, while particle physics and cosmology are located in the bottom right.

(Note 2) White circles indicate the centers of research areas. Research areas had a weak linkage with other research areas were positioned away from the center of the map; therefore they are not depicted in the map. Red dotted lines show the groups of research areas. They are guides for general understanding of research content. A research area included in a group is determined by whether the research area shares common keywords with other research areas on the map. Thus, it is not implied that research areas that are outside the groups are not important.

Exhibit 2 Science Map 2012



Data : *NISTEP conducted analysis and visualization (ScienceMap visualizer) based on ESI research front data (N(ST$P version) by ThomÚoÕ Reuters.*

Research area groups related to life sciences are found in the upper left of the Science Map, as depicted in Exhibit 2. “Cancer research” and “research on cardiovascular disease” include keywords related to clinical research. The research areas of “research on infectious diseases and immunology,” “gene expression control and regenerative medicine,” and “plant and microbiological research” include keywords related to gene expression regulation, showing an elucidation of molecular mechanisms is shared element of research among the three groups. In addition, “research on brain and neurological diseases” as well as “research on psychiatric disease” are closely positioned and therefore thought to be developing cooperatively.

“Public health and physical activity” is located somewhat away from “research on infectious diseases and immunology.” Other groups of research areas in life sciences are conducted from the viewpoint of individual mechanisms and their control or medical treatments, but “public health and physical activity” includes keywords related to group health and preventative measures for public hygiene, indicating a difference in the viewpoint from the former.

“Environmental research,” which is located below “plant and microbiological research” on the Science Map, has shown a visible change from 2002 to 2012. In Science Map 2012, two research area groups were found, namely “environment (research on ecological system)” and “environment (research on climate change).”

“Particle physics and cosmology” is located in the bottom right of the Science Map. Starting from “particle physics and cosmology,” we can find the research area groups of “solid state physics (magnetism and superconductivity),” “solid state physics (quantum information and optics),” “nanoscience (approach from physics),” “nanoscience (approach from chemistry),” and “chemical synthesis” showing inter-linkages of these research area groups. Compared with Science Map 2002, the number of research areas related to nanoscience has shown a sharp increase.

Between the groups of life sciences and nanoscience, there is a group of research areas presenting the intersection of biological mechanisms and nano-level phenomena (i.e., the life-nano bridge). Looking at changes in the map over time since Science Map 2002, it is found that knowledge created in the life-nano bridge is spreading to both the life sciences and nanoscience rather than some fusion research appear and grow. In other words, this portion represents a true intersection of biological mechanisms and nano-level phenomena.

Another characteristic of Science Map 2012 is that at the intermediate position between the research areas of “chemical synthesis,” “plant and microbiological research,” “environment (research on ecological system),” and “environment (research on climate change)," we find a group of research areas related to the creation of energy through biological and chemical approaches, including research areas related to biomass and microbial fuel cells.

The Science Map also includes research areas not categorized into any research area groups. A research area included in a group is determined by whether the research area shares common keywords with other research areas on the map. Thus, it is not implied that research areas that are outside the groups are not important.

(COLUMN) THE RELATIONSHIP BETWEEN RESEARCH ACTIVITIES AND WHAT IS OBSERVED IN NISTEP'S SCIENCE MAP

The Science Map provides a bird's eye view of hot research areas. It can visualize growth, integration, and divisions of the research communities for research areas that continuously exist on the map; however, the Science Map is not a closed world. The Sea of Science, a source of knowledge made up of all scientific papers produced in the world, exists outside the Science Map. New notable research areas are formed and emerged from this Sea of Science and these research areas are monitored on the Science Map.

There are various phases in research, such as a phase heading toward practical application, a phase summarizing research findings, etc. From this viewpoint, we identify the following three types of research areas not detected in the Science Map: (1) research areas that have transitioned into technological phase such as those seen in patents; (2) research areas in a saturation phase; and (3) research areas in a steady state after the temporary boom. Even in these undetected research areas, knowledge is still accumulated and does not disappear. In all these patterns, the research area is expected to reappear on the Science Map if it begins to receive new attention, for example, if there is a discovery that pushes the research into a new phase.

Thus, the Science Map extracts those research areas in which research is receiving extensive attention and is in a progressive phase. This is a "cyclic system" and the system cannot work without the Sea of Science that surrounds the Science Map. Since research areas represent activities of the communities of researchers who share common research interests, dynamics such as changing generations of researchers and movement of researchers across research areas would have some impacts on a cyclic system of Science Map.

(2) Increasing ubiquity of inter-/multi-disciplinary research

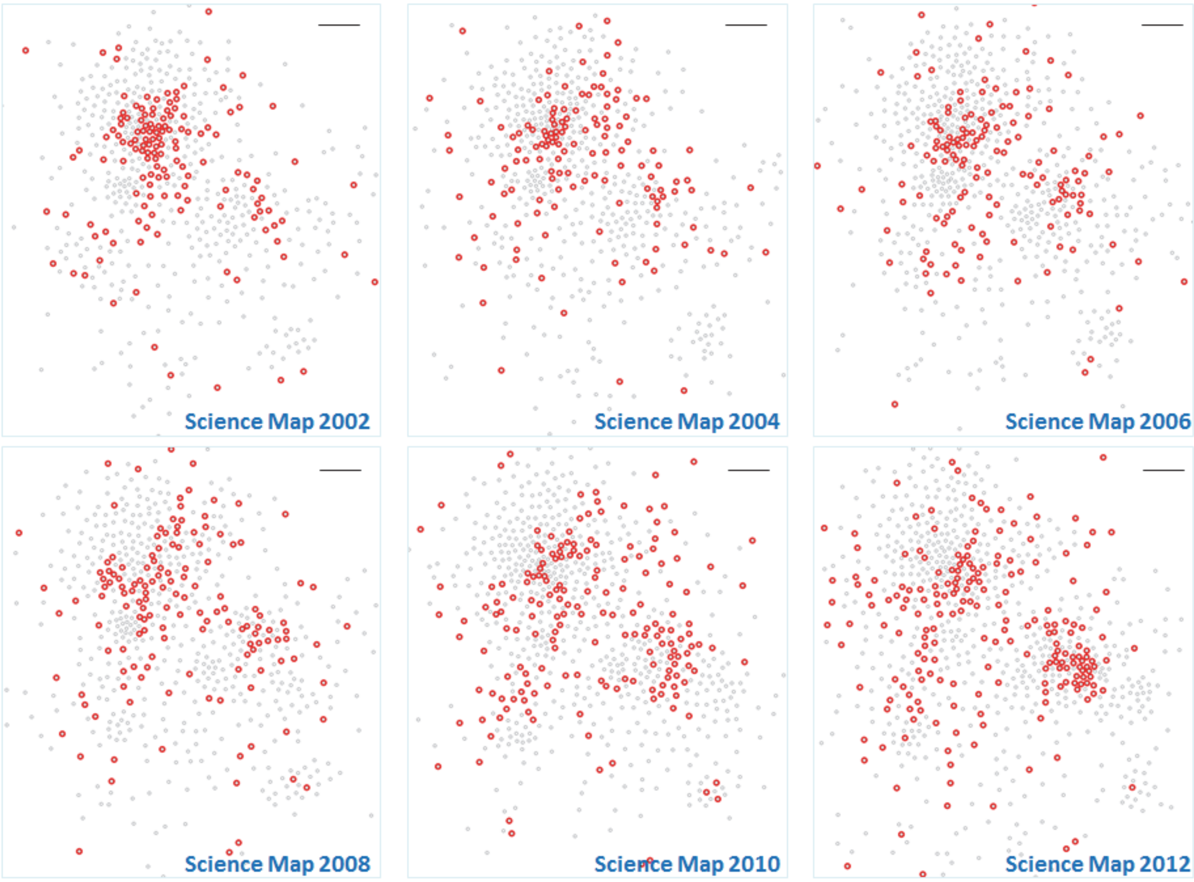
Understanding the trends in inter-/multi-disciplinary research is crucial to grasp the present status of science. The proportion of inter-/multi-disciplinary research areas among hot research areas has changed little since Science Map 2002 and stands at 26% in Science Map 2012.

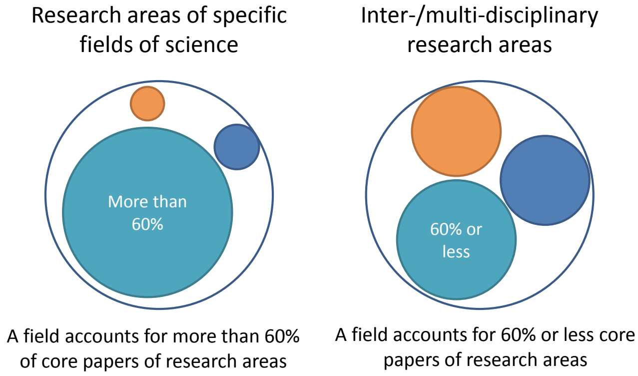
Time-series observation of the position of inter-/multi-disciplinary research areas in the Science Map (shown in Exhibit 3) revealed that research areas localized in relatively limited region in Science Map 2002 show gradual expansion over time.

In Science Maps 2002 and 2004, inter-/multi-disciplinary research areas were concentrated in life sciences. After Science Map 2006, many inter-/multi-disciplinary research areas have appeared in nanoscience. The ubiquity of inter-/multi-disciplinary research is increasing over time and these research areas are located across the entire map in Science Map 2012.

What these findings indicate is that while the exchange of knowledge was common within life sciences at the time of Science Map 2002, we also witnessed an increase in such exchanges in non-life sciences as well as between life sciences and non-life sciences. In other words, it remarks growing importance of the combination of knowledge of different fields of science in the advancement of contemporary science.

Exhibit 3 Changes in the position of inter-/multi-disciplinary research areas on the Science Map





(Note 1) Circles represent research areas. If a specific traditional field accounts for less than 60% of core papers, we define these research areas as inter-/multi-disciplinary research areas and show them with red circles.
(Note 2) The length corresponding with 10-unit distances is shown on the map as a scale.
Data : NISTEP conducted analysis and visualization (ScienceMap visualizer) based on ESI research front data
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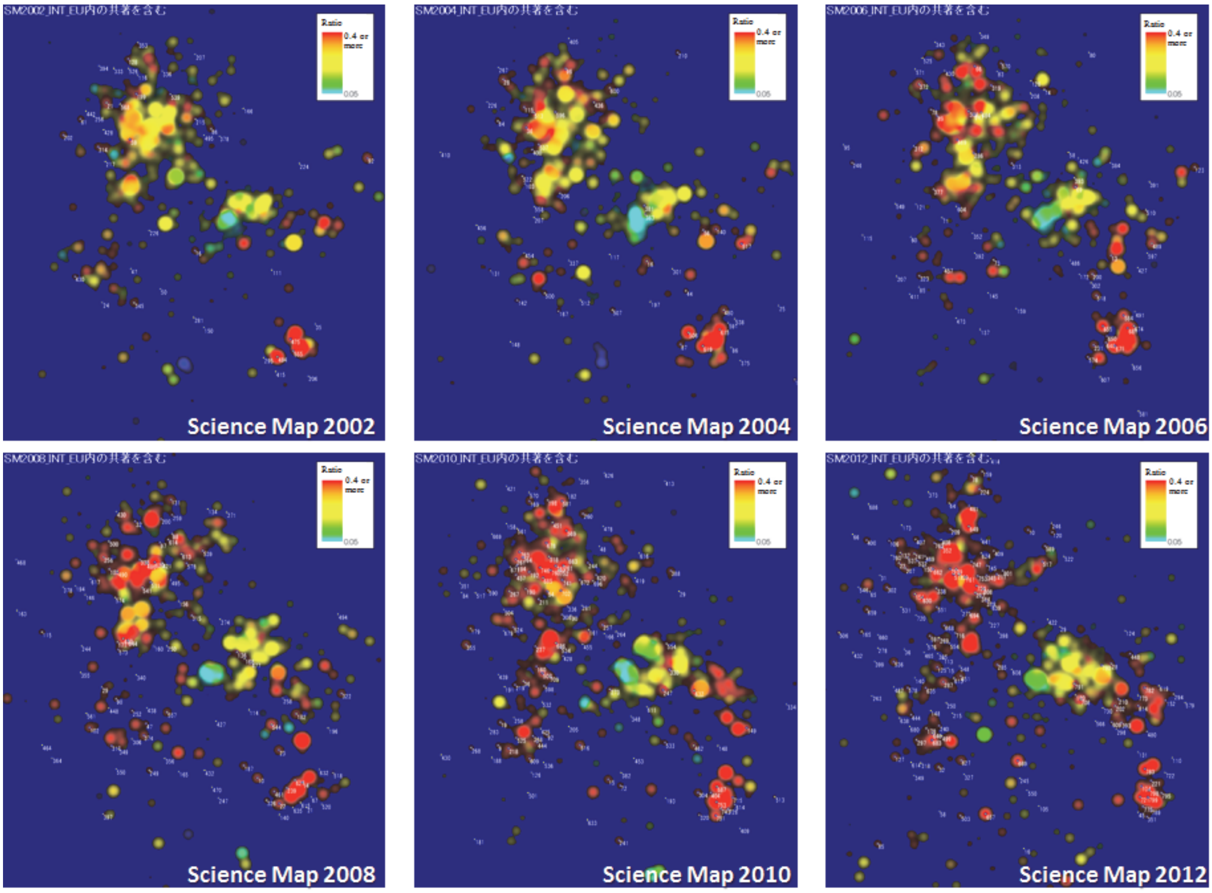
(3) International collaboration is getting a common mode of creation of high impact knowledge even in life sciences

Analyses of the type of authorship in scientific papers showed the increasing of internationally co-authored papers, which can be considered as an output of an international collaboration. This observation indicates that research activities are being conducted across national and regional borders. By overlaying information of international co-authorship in core papers of each research area over the Science Map, we analyzed current status of international collaboration in hot research areas.

Exhibit 4 displays the ratio of international co-authorship in core papers overlaid on Science Maps. The red color represents region where the ratio of international co-authorship is 40% or more. In Science Map 2002, the red colored region is concentrated in “particle physics and cosmology;” however, the ratio of international collaborations shows a gradual increase on the entire Science Map over time.

An increase in the ratio of international co-authorships has especially been clear in life sciences. In contrast, the ratio of international collaboration has remained low in “chemical synthesis” and “nanoscience” from Science Maps 2002 to 2012. This shows that the forms of research activities vary depending on the content of research and that the ratio of international co-authorships is not uniform on the Science Map.

Exhibit 4 Ratio of international co-authorships overlaid on the Science Map over time



(Note) *The regions where the ratio of international co-authorship is 5% are shown in light blue; over 40% are shown in red; yellow circles and numbers represent locations and IDs of research areas where the ratio of international co-authorship in core papers are over 40%.*

Data : *NISTEP conducted analysis and visualization (ScienceMap visualizer) based on ESI research front data*
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(4) Japan's falling share and diversity in the Science Map

We monitored three indicators to analyze Japan's presence in scientific research.

The first indicator is the share of Japan and benchmarking countries in core papers that made up of all research areas (see Exhibit 5A). This is an indicator that shows a volume of papers that lead hot research areas. On Science Map 2012, the UK (6.9%) and Germany (7.2%) lead Japan (4.1%). Furthermore, we observe that Japan's share is falling over time.

Second, by looking at the number of research areas Japan participating[2] on Science Maps, we analyzed Japan's diversity in scientific research as shown in Exhibit 5B. While the number of research areas in the Science Map increases, the number of research areas Japan participating has stagnated, leading to a decline in the coverage on Science Maps (41% as of Science Map 2008 and 33% as of Science Map 2012). There is a significant difference between the number of research areas Japan participating and the UK and Germany participating.

Third, by analyzing the coverage in citing papers (top 10%), i.e., followers of the core papers, we can check the size of research community of the second tier group. The number of research areas each country participating in citing papers (top 10%) was higher than that in core papers for all three countries, but the UK (720) and Germany (702) still show large advantage over Japan (607). This result indicates a lack of the second tier group in Japan compared to the UK and Germany.

Moreover, if we compare the ratio of the coverage in core and citing papers (top 10%), we find that while Japan stands at 45% (274/607), the UK and Germany are at 70% (504/720) and 65% (455/702), respectively. How to facilitate the transition of researchers of the second tier group to the first tier group is another issue for Japan.

[2] *The participation to a research area is determined by whether or not a core paper (or a top 10% citing paper) of a target country is included in a research area.*

Exhibit 5 Japan's presence on the Science Maps

(A) Shares of Japan and benchmarking countries in core papers (18,515 core papers for 823 research areas)

Share of Core papers	USA	Germany	UK	Japan	France	South Korea	China
Science Map 2008	46.4%	7.2%	6.7%	5.3%	3.7%	1.0%	5.2%
Science Map 2010	42.4%	6.9%	6.9%	4.7%	3.9%	1.1%	6.4%
Science Map 2012	40.6%	7.2%	6.9%	4.1%	3.8%	1.4%	9.2%

(B) Changes in the coverage of research areas Japan, the UK, and Germany participating. (1) One or more core papers, (2) One or more citing papers (top 10%)

Coverage of RAs			ALL	Japan		UK		Germany	
			Num. of RAs	Num. of RAs	Coverage	Num. of RAs	Coverage	Num. of RAs	Coverage
(1)	Science Map 2008	Core papers	647	263	41%	388	60%	366	57%
	Science Map 2010	Core papers	765	278	36%	488	64%	447	58%
	Science Map 2012	Core papers	823	274	33%	504	61%	455	55%
(2)	Science Map 2012	Citing papers (Top10%)	823	607	74%	720	87%	702	85%

(Note 1) Exhibit (A) shows the share of Japan and benchmarking countries in core papers that form all research areas using fractional counting method.

(Note 2) The number of research areas in Exhibit (B) indicates the number of research areas in which the country has (1) one or more core paper and (2) one or more citing papers (top 10%).

Data : NISTEP conducted analysis and visualization (ScienceMap visualizer) based on ESI research front data

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3. Categorization of research areas by using the Sci-GEO chart and understanding current activities of Japan

(1) Current situation of Japanese S&T policy and reason why we created the Sci-GEO chart

In recent discussions of science and technology policies in context of research activities that produce scientific papers as an output of research, various issues have been raised, including basic research as a seedbed of innovation, diversity in basic research, and selection and concentration of resources; however, these policy discussions are often conducted without sufficient quantitative evidences, and policies are often advanced based on past experience or measures taken abroad. Unfortunately, Japan's presence grasped on the Science Map is falling over the past decade.

Due to current financial situation of Japan, the allocation strategy is critical in S&T policy. In such a context, quantitative evidences should be constructed and policy discussions and decisions should be made based on these evidences.

What research areas are responsible for diversity in basic research? Which research areas are candidates for selection and concentration of resources? How should we think about the balance between diversity in basic research and selection and concentration of resources? To answer these questions, this Science Map introduces the concept of Sci-GEO chart (Chart represents geographical characteristics of Research Areas on Science Map).

(2) Categorization of research areas by using the Sci-GEO chart

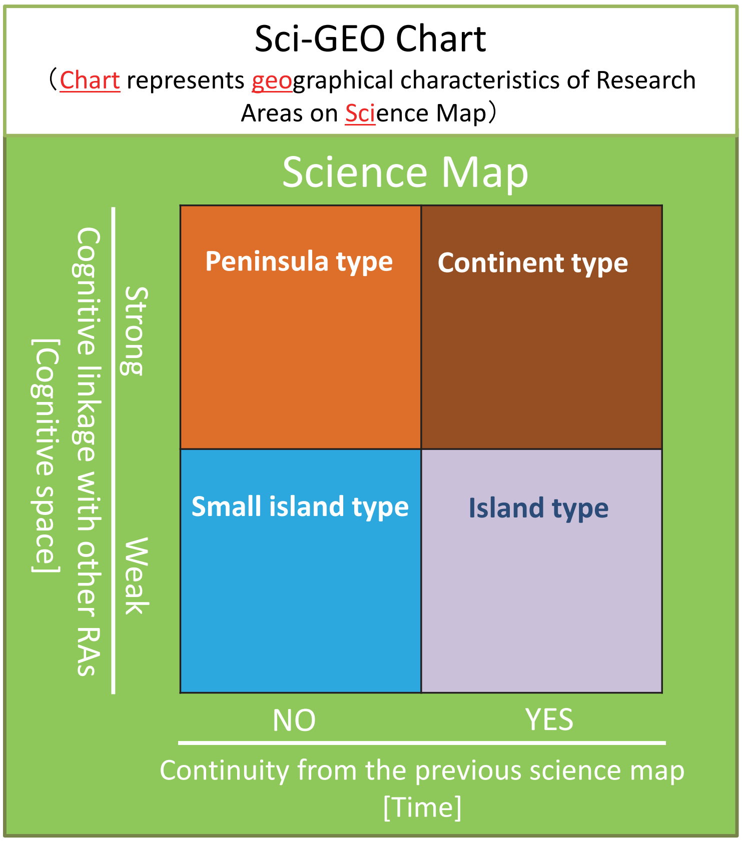
Looking at the dynamic changes on the Science Map[3], the mountain of scientific research can be classified into two portions. The first are relatively "hard" portions, where scientific research is continuously taking place and strong relationships with other research areas exist. The second are "soft" portions showing continuous changes. To categorize these "hard" and "soft" portions, we introduced the concept of the Sci-GEO chart on the Science Map, as shown in Exhibit 6.

In the Sci-GEO chart, research areas are categorized using continuity (time axis) and the strength of relationships with other research areas (cognitive axis). As shown in Exhibit 6, when there is continuity with the previous map, we categorize the research areas into "continent type," which are strongly related to other research

[3] *A movie showing dynamic changes from Science Map 2002 to Science Map 2012 is available at https://www.youtube.com/watch?v=ZjgvboKRE1o (in Japanese)*

areas, and “island type,” which have weaker relationships with other research areas. In case there is no continuity with the previous map, we categorize those research areas as “peninsula type,” which fill peripheral positions of “continent type” research areas, and “small island type,” which have weaker relationships with other research areas.

Exhibit 6 Categorizing research areas by using the Sci-GEO chart



(Note1) Regarding links with other research areas, research areas are said to be linked if the degree of normalized co-citation is 0.02 or more. Three or more links are considered to be a strong linkage. Two or less links are considered to be weak linkages.

(Note2) Continuity refers to 20% or more core papers overlapping between research areas in the Science Map being compared.

(3) Trends in research activities in the world and benchmarking countries as seen with the Sci-GEO chart

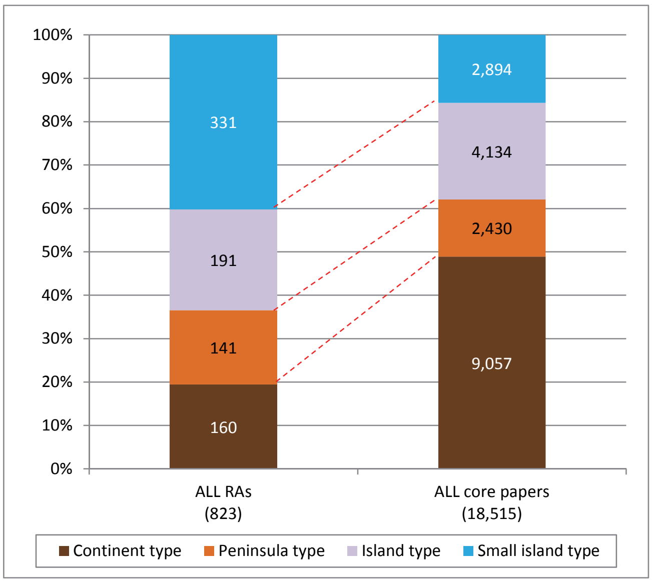
Among the 823 hot research areas obtained in Science Map 2012, it is found that 40% of the research areas are small island type and 20% are continent type, as depicted in Exhibit 7A. In contrast, looking at the number of core papers in the research areas, we find that 50% are in continent type and less than 20% are in small island type, reflecting large size of continent type research areas relative to small island type research areas (60 core papers for continent type vs. 10 core papers for small island type)

Among the 274 research areas Japan participating, 90 are continent type, 55 are peninsula type, 59 are island type, and 70 are small island type, as shown in Exhibit 7B. Comparing Japan, the UK, and Germany, we find the largest difference in the number of small island type research areas. Looking at the balance of Sci-GEO types, it is found that 26% of Japan's participating research areas are small island type and 33% are continent type. The balance shows striking difference compared with the balance of Sci-GEO types in the world (40% small island type, 19% continent type).

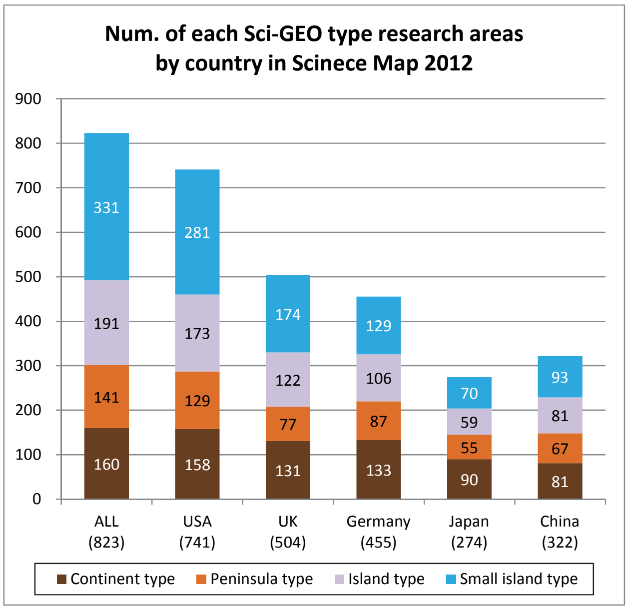
These evidences pose crucial questions regarding how Japan should think of its "presence" in scientific research. Dose Japan need to increase research diversity as seen through the number of research areas Japan participating? Or does Japan need to increase the volume of high impact papers to secure its share in the world? Depending on this choice, desirable balance in Sci-GEO chart will differ.

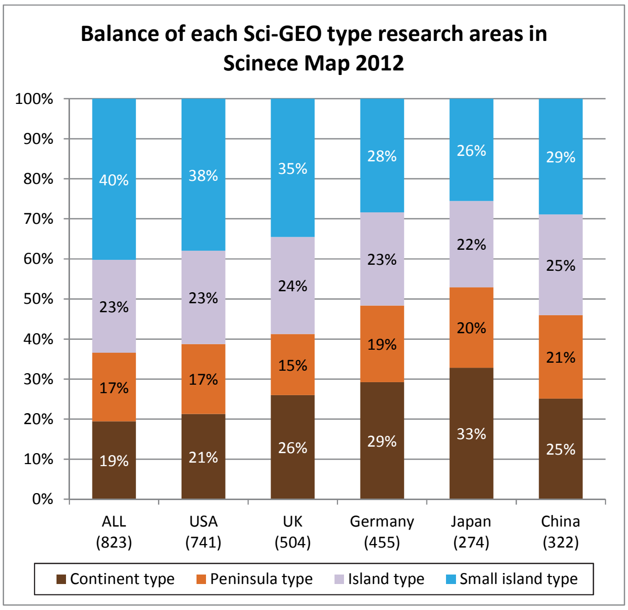
Exhibit 7 Comparison of Japan and benchmarking countries based on the Sci-GEO types

(A) Balance of the number of research areas and the number of core papers by Sci-GEO type in Science Map 2012



(B) Number of each Sci-GEO type research areas by country and their balance on Science Map 2012





Data : NISTEP conducted analysis and visualization (ScienceMap visualizer) based on ESI research front data (NISTEP version) by Thomson Reuters.

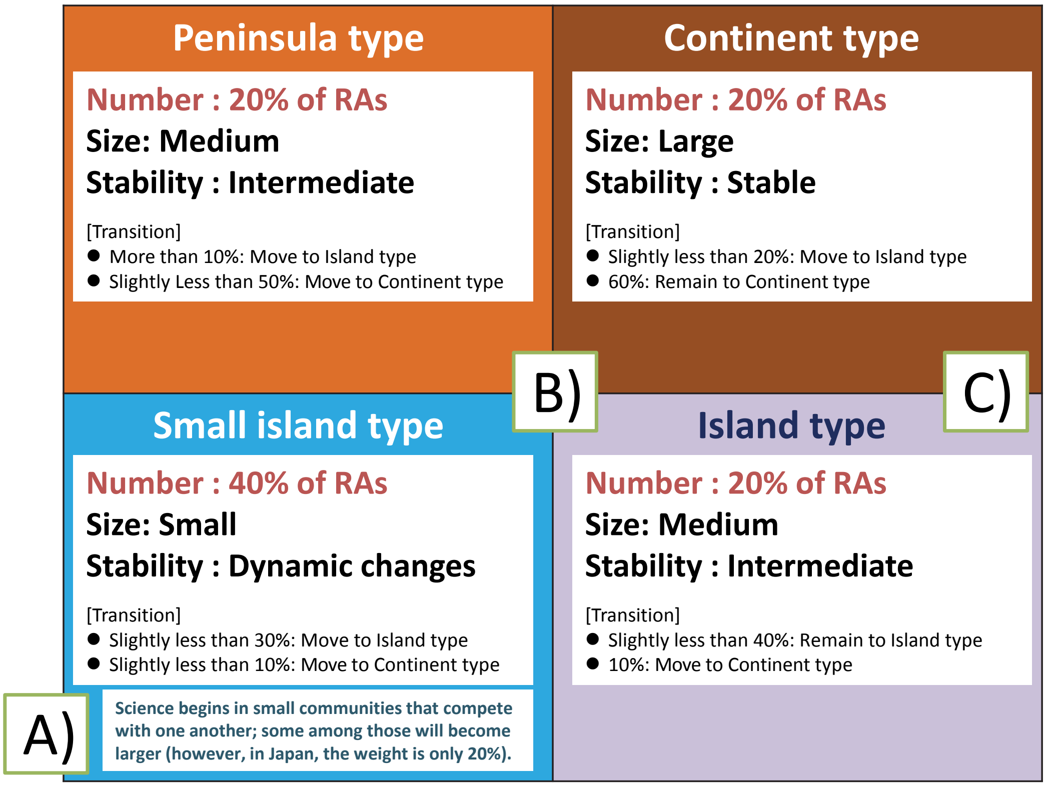
(4) Transition of Sci-GEO types over time

To look at the evolution of research areas by using the Sci-GEO chart, we analyzed the transitions of Sci-GEO types of research areas between the successive two Science Maps, as illustrated in Exhibit 8.

Small island type research areas account for 40% of research areas and therefore they play major role in the diversity of research. Analyses of transitions among Sci-GEO types revealed that small island type research areas evolve to other Sci-GEO types over time, such as island type (slightly less than 30%) and continent type (slightly less than 10%); however, approximately 60% of the small island type research areas are not detected on the subsequent Science Map, showing highly active replacements. These facts suggest that the two points are crucial for promoting research of small island type. First, an environment in which these research areas can be actively generated must be created. Second, to allow the continuous development of promising small island type research areas, support should be provided at proper timing in order to increase the size of the community participating in these research areas.

Approximately 60% of the continent type research areas also appear on the subsequent Science Map as continent type. Slightly less than 20% of them shows transition to island type and those slightly more than 20% are not found on the subsequent Science Map. Overall, 70% of continent type research areas continue, showing a high degree of stability. Looking at continent type research areas from the viewpoint of continuity, we find that these research areas are more stable targets for research promotion in comparison with other type of research areas. However, large size of research areas relative to the other Sci-GEO types indicates fierce international competition in the research areas. Therefore any measures to promote research must consider the scale of resources to be invested as well as a balance between competition and collaboration.

Exhibit 8 Features of each Sci-GEO type research areas and the points to be considered for promoting research



A) How to obtain diversity? → It includes RAs with a possibility of growing larger in the future
B) How to select and support RAs that may grow larger in the future?
C) How to maintain presence of Japan in these RAs and to achieve scientific and social/economic impacts?

(5) Analyzing characteristics of funding by using the Sci-GEO chart

Results presented so far suggested that optimal policies for promoting research (number of projects, research team scale, amount of research budget, etc.) differ across the type of a research area as found through the Sci-GEO chart. Next, we analyzed the relationship between funding and the Sci-GEO types on the Science Map. In particular, we overlaid the positions of scientific papers that got support from Japan's two major competitive funds — grants-in-aid for scientific research ("KAKENHI") and the ones by Japan Science and Technology Agency (JST) — on the Science Map. In the following results, "WoS-KAKEN paper" refers to a paper that is listed in a report of a research project supported by KAKENHI. "JST paper" refers to a paper in which JST is listed as one of affiliation of authors.

Research areas including WoS-KAKEN papers account for approximately 70% of the research areas Japan participating, as shown in Exhibit 9. In other words, KAKENHI is responsible for a large portion of the diversity of research in Japan. Research areas including JST papers largely overlap with research areas including WoS-KAKEN papers; among them, the more overlapping is found in island and continent type research areas. While it has often been pointed out that KAKENHI supports the diversity of Japanese research and JST strategically promotes research, we have now shown this picture quantitatively.

As shown in previous analyses, Japan's share of papers is decreasing and diversity of research is not catching up the expansion of scientific research in the world. Discussions should be made regarding how to effectively bridge funding agencies in order to increase the presence of Japanese research and how to provide appropriate amount of research funds reflecting stage of evolution and characteristics of research areas. At the same time, the effort to accumulate additional evidences for further policy discussions is inevitable as described in future works.

Exhibit 9 The number of research areas including WoS-KAKEN papers and JST papers by Sci-GEO type on Science Map 2008

	Number of research areas				Share of overlapping RAs in RAs WoS-KAKEN papers included
	Science Map 2008	JAPAN participating	WoS-KAKEN papers included	JST papers included	
Small island type	248	64	45	7	13%
			Overlapping RAs 6		
Island type	169	77	59	27	46%
			Overlapping RAs 27		
Peninsula type	92	35	25	4	12%
			Overlapping RAs 3		
Continent type	138	87	74	25	32%
			Overlapping RAs 24		
Total	647	263	203	63	30%
			Overlapping RAs 60		

(Note1) *This analysis used the Science Map 2008.*
(Note2) *"WoS-KAKEN paper" refers to a paper that listed in a report of a research project supported by KAKENHI.*
(Note3) *"JST paper" refers to a paper in which JST is listed as one of affiliation of authors.*
Data : *NISTEP conducted analysis and visualization (ScienceMap visualizer) based on ESI research front data (NISTEP version) by Thomson Reuters.*

4. X-ray images of research activities at the institutional level on Science Map 2012

As shown in Exhibit 10, we include information regarding each of the 823 research areas found on Science Map 2012, such as the information of the number of core papers, the share of benchmarking countries, keywords, and the proportion of internationally co-authored papers[4].

We also visualize research activities of 153 Japanese universities and public research institutions on Science Map 2012. It is a kind of X-ray image enabling us to capture institutional-level research activities in Japan. By using this data, we compare the characteristics of Japan's universities and public research institutions from a quantitative viewpoint. Exhibit 11 presents the Science Map Research Activity Sheet of University of Tokyo.

We analyze how research activities of the 153 universities and public research institutions overlapped on the Science Map and find that there are research areas over 20 institutions participating (as shown in Exhibit 12). We also find that there are approximately 90 research areas in which only one institution are participating, indicating the research area level analysis well reveals an individual characteristic of universities and public research institutions.

Here, we will provide examples of how to utilize the data. In a situation where an institution sets integrated research agenda to promote research, they can confirm if their institution covers research areas that would fit the research agenda or how distant are the candidate researchers on the map, using the tool as a common basis of discussion. In addition, this report includes accession number (unique ID of papers in the Web of Science) of core and citing papers (top 10%) of 153 universities and public institutions for searching publications. If the institution contributes in various research areas, it could classify publications by department or research units and analyze their locations on the map in order to visualize the characteristics of the institution.

We hope that utilization of this quantitative monitoring tool will deepen discussion and will increase the good practices at individual research institutions. Consequently, we will see an accumulation of knowledge related to research planning based on such evidence. The experience would be beneficial for further advancement of Science Map research, thus we would be grateful to hear about practical cases on how this tool is being utilized.

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[4] *The information is only available in Japanese.*

Exhibit 10 Detailed research area data on the Science Map 2012

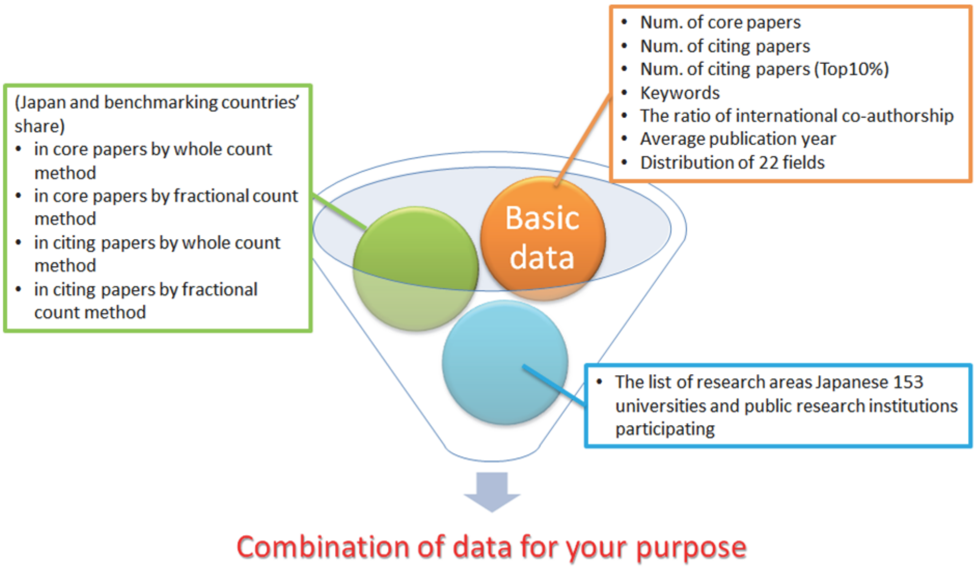
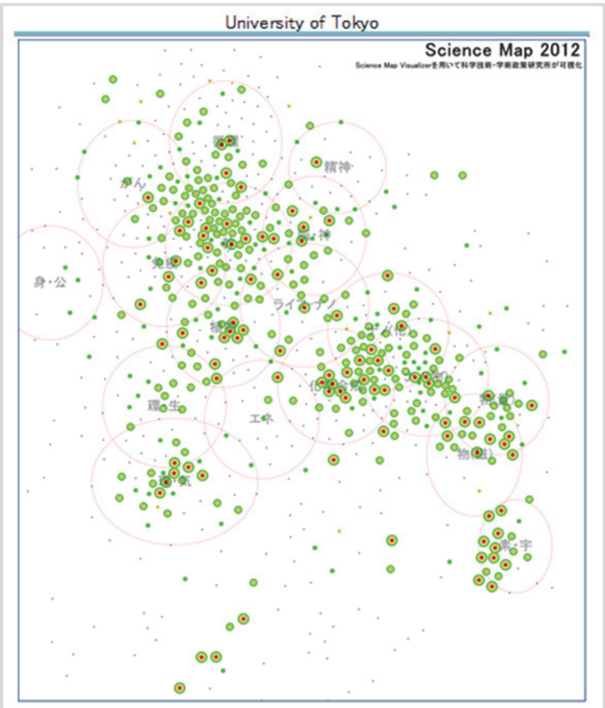
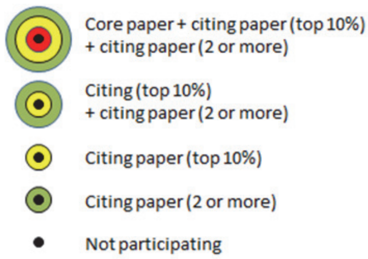


Exhibit 11 Science Map Research Activity Sheet

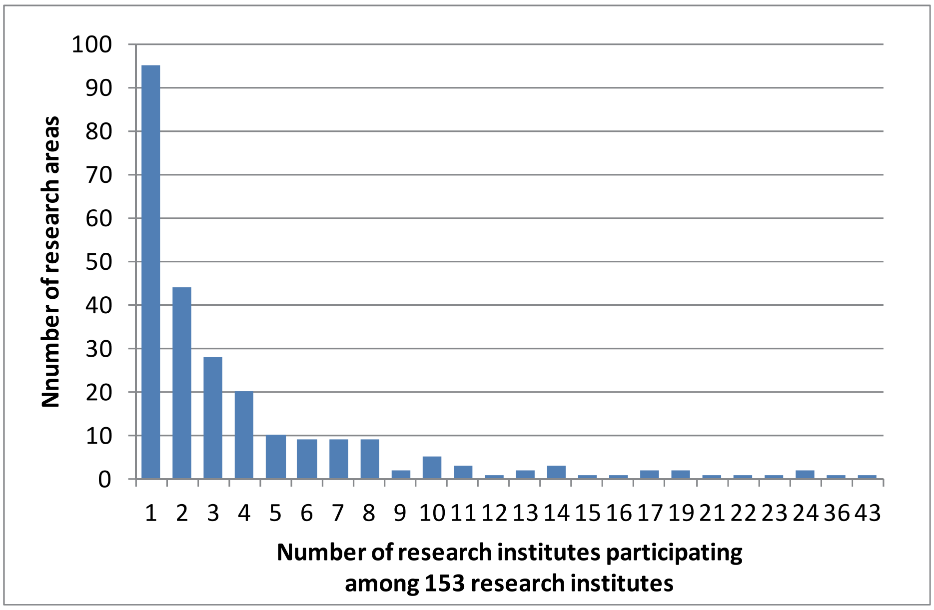




University of Tokyo	Core papers		Citing papers (Top10%)		Citing papers	
	Num. of RAs	Num. of papars	Num. of RAs	Num. of papars	Num. of RAs	Num. of papars
Science Map 2008	85	287	313	1,959	341	5,797
Science Map 2010	103	305	348	2,088	409	6,088
Science Map 2012	99	301	309	2,089	402	6,674

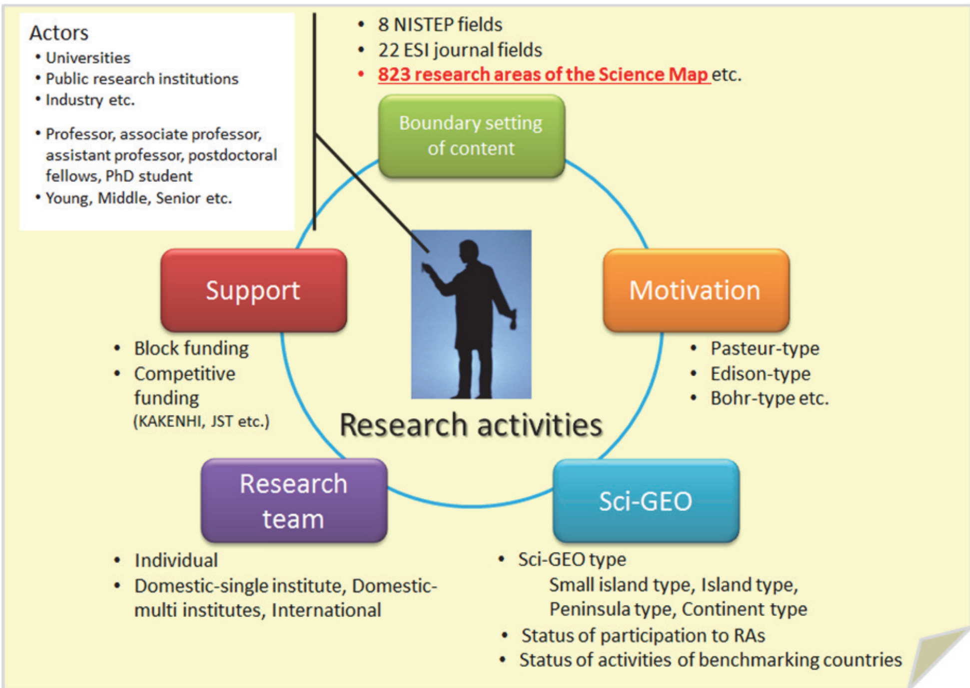
Data : NISTEP conducted analysis and visualization (ScienceMap visualizer) based on ESI research front data (NISTEP version) by Thomson Reuters.

Exhibit 12 Distribution of Japanese research institutes in research areas of the Science Map 2012



Data : *NISTEP conducted analysis and visualization (ScienceMap visualizer) based on ESI research front data (NISTEP version) by Thomson Reuters.*

Exhibit 13 Elements necessary when considering the activities of research



5. Future works

Finally, we discuss future work. In Exhibit 13, we summarized the elements necessary when considering the activities of research based on our past studies and discussions with government officials and high-level policy makers. When analyzing research activities, the following five elements should be taken into consideration; (1) boundary setting of content, (2) motivation, (3) Sci-GEO type, (4) the composition of research team, and (5) the kind of supporting funds.

In this report, we tried to overlay various information of the above mentioned research activities on the Science Map. In other words, by linking the five elements to the Science Map, we attempt to obtain an integrated understanding of research activities. It is expected that our understanding of these factors will bring a qualitative change on our discussions of S&T policies. For example, in discussing internationalization of research, the Science Map shows how the status of internationalization differs depending on a research area and how the UK and Germany have gained their coverage of research areas through internationalization. In addition, another study suggests that compared with Edison-type research, in which solving specific issues in real life is the primary motivation of research, Bohr-type research projects, which is motivated by the pursuit of basic principles, have a higher likelihood of evolving to an international collaboration. These data is expected to clarify the meaning of internationalization in S&T policies.

Linking data of the types and amounts of research funding to the Science Map will lead to the in-depth understanding of the appropriate funding and team sizes for promoting research. As seen in the Sci-GEO chart analysis, 40% of research areas receiving global attention are classified as small island type, which are often to be replaced, and approximately 20% are continent type, which have strong relationships with neighboring research areas. The allocation of research funding should be re-examined; depending on the balance between these two types of research Japan would pursuit.

After around ten years of trial and error, we have obtained effective tools and indicators to analyze research activities, such as that given in this report. In future work, by linking various elements of research activities such as those shown in Exhibit 13 to the Science Map, we would be able to further deepen our analysis.

In summary, we outline three issues for future work as following.

LINKING THE SCIENCE MAP AND FUNDING DATA

Adding funding data to the Science Map will provide valuable information. By overlaying WoS-KAKEN paper data on Science Map 2008, it becomes clear that KAKENHI plays an important role in the diversity of Japan's research. Adding information about the amounts of research funding in addition to the names of funding programs, it would be possible to obtain various data regarding the effects of research funding on the progress of scientific research by analyzing its relationship with funding over time.

Achieving this requires information of funding data and outputs of the funding; however in Japan, KAKEN database (https://kaken.nii.ac.jp/) is the only publicly available database that chronologically collects such information regarding funding and its outputs. Currently, there is a time lag between the filing of reports of research projects and the registration of the reports to the KAKEN database. Furthermore, matching of papers registered in KAKEN database and records in the Web of Science are needed. At present, it is technically difficult to put the latest information of various research funds on the Science Map.

A method for linking funding information to the Science Map in real-time would be to utilize the acknowledgments described in papers. Some paper databases are beginning to record acknowledgment information for papers dating back to the late-2000s; however, acknowledgments are not always written in the same format and often cannot be utilized as original expression. Standardized way to describe the funding information in the acknowledgment should be determined in each funding agency.

In the future, by introducing the "standardized acknowledgment codes" in all funding agencies in Japan, similar to the patent application numbers, it should be possible to perform real-time monitoring of output data through paper databases.

LINKING SCIENCE AND TECHNOLOGY

The observable range of the Science Map is limited to science where research results can be presented in the form of papers. To observe science and technology from a bird's eye view perspective, we had better to construct a technology map that can grasp the trends of technology development through information such as patents. By using the paper information cited in patent documentation, we could link a technology map to the Science Map and observe the transfer of knowledge from science to technology and vice versa.

By combining this with the funding information mentioned above, we could measure the real effects of public funding on the development of science and technology.

UTILIZING SCIENCE MAP AS AN ARENA FOR DISCUSSION

This report lists information, such as the number of core papers, the shares of benchmarking countries, and the ratio of international collaborations in each of the 823 research areas on Science Map 2012; such information is to be utilized by those individuals involved in Japan's science and technology policymaking as well as the management of Japan's universities and public research institutions. We also constructed the "Science Map Research Activity Sheet," which visualizes how 153 universities and public research institutions are participating in the research areas found on Science Map 2012.

We hope that by deepening the discussion of research management through utilizing this kind of quantitative monitoring tool, we can increase good practices, and consequently, Japan's universities and public research institutions will accumulate knowledge about management at the organizational level.

When discussing research agenda setting, individual researchers and policymakers tend to express their opinions based on their backgrounds as a member of advisory board. We believe that providing common information of discussion such as the Science Map would help discussion among them with different backgrounds, where they can utilize the map as a common basis for discussing research planning. By sharing the same "arena," researchers and policymakers can conduct discussions while properly considering the distance among them. The experience of these discussions would be beneficial for further advancement of Science Map research, thus we would be grateful to hear about practical cases on how this tool is being utilized.

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