

## Survey analysis of Japanese mathematics research

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# Survey analysis of Japanese mathematics research

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**Abstract.** Despite the acquisition of expertise in mathematics during primary and secondary education, Japan is not sufficiently utilizing its expertise in mathematics from a global viewpoint. Simultaneously, researchers from the industry and other fields in Japan have high expectations for mathematics. This manuscript surveys these issues from a macro perspective and clarifies these situations along with the structural bottlenecks underlying the neglect of mathematics research in Japan's science and technology policy; initiatives undertaken by the Japanese government, which has taken cognizance of this situation, are also discussed.

*Keywords.* mathematics, industry, other fields

## 1. INTRODUCTION

The author will try to analyze the current Japanese mathematics research from a viewpoint of a nonmathematician in view of other countries. Lack of this kind of observations by outsiders prevents open discussions between mathematicians and non-mathematicians who need mathematics.

In this paper, for such an observation which is the basis of this paper, the author needs several indices. Otherwise it would be impossible to make any proposal for possible improvements of the Japanese mathematics. One of such indices is the SCI database. The author does not mean that the SCI index is uniquely available, but it is widely used over the world, and we can consider it as sufficiently reasonable index. Other indices are the number of keynote addresses and invited speakers at ICM and ICIAM, mathematics research expenditure, and so on.

## 2. PERFORMANCE OF AND RESOURCES USED IN MATHEMATICAL RESEARCH

Japan is a world leader in research and development expenditure, ranking second in the world behind the USA. Moreover, according to Thomson Scientific's Web of Science Citation Index (SCI) database [1], Japan ranks second behind the USA, in all fields as a whole. In mathematics, however, the top three are the USA, China, and France, with China having surpassed Germany and France in the past few years [2]. Japan stands in the seventh place behind these countries and the UK or Italy (see Figure 1).

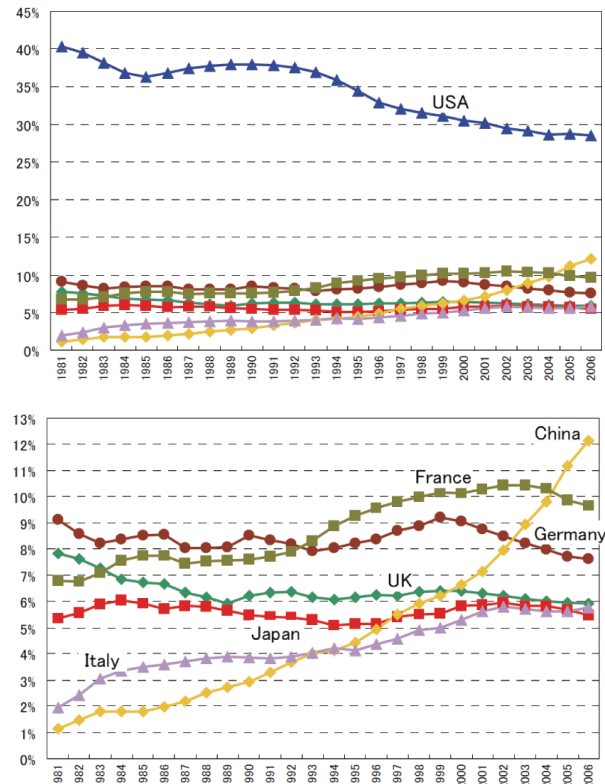


Figure 1: World share of mathematics research papers published by major countries (Three-year weighted averages; the figure on the lower is an Scientific's Web of Science (1981-2006))

In order to verify the suitability of Japan's position, this author examined the world share of the number of mathematics research papers published as against that of a number of research papers published in all fields (with weights for mathematics research) for major countries and their

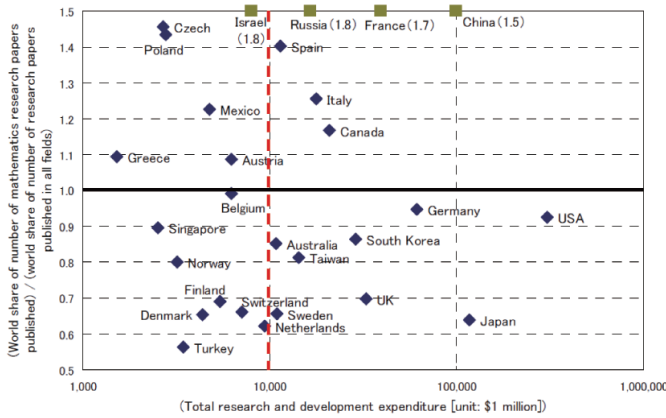


Figure 2: Relationship between total research and development expenditure in major countries with weights for mathematics Research (2002-2006 average; prepared based on the information obtained from Thomson Scientific's Web of Science (1981-2006) and the IMD World Competitiveness Yearbook)

relationship with the total research and development expenditure (see Figure 2). As illustrated in Figure 2, in smaller countries with relatively low total research and development expenditure due to factors such as the scale or economic conditions (Group 1), the promotion of science and technology tends to be limited to specific fields or areas. It appears that such governments are obliged to choose whether to include mathematics in their science policies. On the other hand, countries having the ability to undertake broad research and development (Group 2) have more exhaustive target science and technology fields, with less scattering of weight for mathematics research. This suggests the possibility that the promotion of mathematics research may be essential to science, technology, and industrial development. Viewing these elements comprehensively, it can be inferred that Japan's mathematics research position is unusual as compared with that of other major countries.

The rebuttal is assumed that the comparison between countries concerning mathematics is completely meaningless between Japan and other country because the definition of "Mathematics" is greatly different. The opinion says that mathematics in Japan has disadvantage in the comparison because mathematics research in Japan is mostly pure mathematics, while mathematics in the USA or Europe contains the applied mathematics and statistics, and especially a large amount of thesis are written and the research expense is bulky in these areas.

This opinion is not reasonable though it reflects realistically the feature of mathematics research in Japan. For instance, the range of "Biotechnology" in the USA and that in Japan are not so different. Neither be that in "Nanotechnology". Why should be only "Mathematics" "greatly different"? Certainly, there are scientific fields in the humanities and social science where there is a considerable difficulty in comparing between each country for depending greatly on the feature of the country situation or the language. However, mathematician oneself insists that math-

ematics has universality exceeding time and space, and of course, countries. There is no reason why mathematics research in Japan should be different from that in the USA or Europe.

The insistence of meaningless comparison between countries confesses that mathematics research in Japan maintains somewhat distorted structure compared with other countries.

Even if the author admits the difference, this implies that the applied mathematics greatly lacks in the Japanese mathematics, and as a result, does not change the status of the Japanese mathematics. Because it is a worldwide thinking that the applied mathematics is not separable from the pure mathematics, and that they both should be considered as the whole of mathematics.

Furthermore, Japan ranks seventh in terms of keynote addresses and invited speakers at the International Congress of Mathematicians (ICM) (see Figure 3) and Japan ranks fifth at the International Council for Industrial and Applied Mathematics (ICIAM) [3]. Those verifies the results of the above analysis on the number of research papers published.

Country	1986 (in USA)	1990 (in Japan)	1994 (in Switzerland)	1998 (in Germany)	2002 (in China)	2006 (in Spain)
1 USA	(66)	63	78	90	78	89
2 France	18	19	21	23	26	28
3 Russia	35	19	8	2	7	3
4 Germany	10	7	9	(15)	9	10
5 UK	5	7	7	8	7	13
6 Israel	5	4	4	9	10	6
7 Japan	3	(24)	3	7	6	7
8 Switzerland	2	1	(5)	4	7	6
9 Italy	5	1	1	5	5	4
10 Canada	1	3	5	3	3	5
...	...	...	...	...	...	...
21 China	1	0	2	0	(16)	1

Figure 3: Keynote addresses and invited speakers at the ICM, By country (The table has been compiled based on the information obtained from the ICM Proceedings and the ICM website. The numbers in parentheses indicate participants from that year's host country. Countries are listed in order of their number of keynote addresses and invited speakers during the period 1986-2006, excluding their years as host country. Note that Russia was the host country in 1986 and the USSR in 1990; Germany does not include East Germany (this holds below as well).)

We now discuss the issue of governmental mathematics research funding. Japan and Germany are not included in the totals for the government funding of mathematics research. In Japan's case, research themes in some areas ("Exploratory Research," "Young Scientists," "Scientific Research (S), (A), (B), or (C)," and "Encouragement of Scientists"; the former categories were comprehensive, general, and experimental research) funded with Grants-in-Aid for Scientific Research (competitive grants in response to applications from researchers) by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the Japan Society for the Promotion of Science (JSPS) have been classified into academic fields such as physics or chemistry. The amount of research funding for themes in mathematics field can be calculated. The Japanese government provides mathematics research funding besides the

Grants-in-Aid for Scientific Research (e.g., Global COE Program); however, there is no formal statistics for mathematics research funding in Japan, therefore the author refrains from the specification. At the OECD purchasing power parity (PPP) rate, the USA government's mathematics research funding was \$690 million, whereas that of the French government was \$170 million (see the year 2005 in Figure 4). Roughly comparing this to the grant funding for basic research, while the USA National Science Foundation's (NSF) mathematics research funding is \$200 million (5.3% of all fields; see the year 2005 in Figure 5) and Germany's Deutsche Forschungsgemeinschaft (DFG) funding is \$41 million (2.6%), mathematics research funding of Japan's Grants-in-Aid for Scientific Research is only \$15 million (1.9%). Furthermore, in contrast to the trends at the USA NSF and Germany's DFG, the percentage of Japan's Grants-in-Aid for Scientific Research allocated to mathematics has been declining since the late 1990s (see Figure 5).

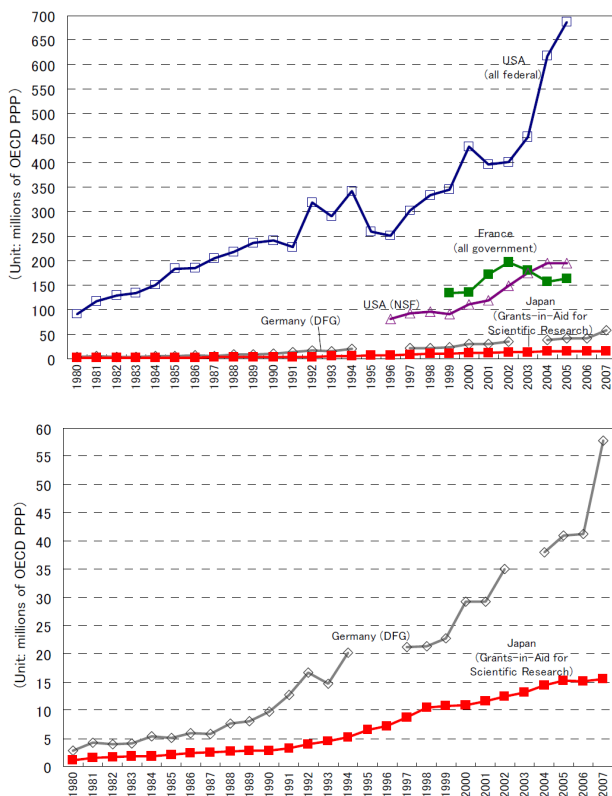


Figure 4: **Government funding of mathematics research in major countries** (The figure on the lower is an enlargement of the one on the upper; it has been prepared based on the information obtained from the directory of adopted themes and public subscription review of Grants-in-Aid for Scientific Research (GyoseiCorp., Japan), Federal Funds for R&D (NSF, USA), Science and Engineering Indicators (NSF, USA), Recherche et développement en France (France), and Bundesbericht Forschung, Faktenbericht Forschung (BMBF, Germany))

The amount of subsidies for operating expenses (ordinary expenditures for education and research at national universities) allocated to Japanese mathematics research appears to exhibit a downward trend. In Japan, therefore,

funding for basic research in fields such as mathematics is showing a tendency of becoming increasingly dependent on Grants-in-Aid for Scientific Research, while the total amount of funding for mathematics research is much lower than that in other major countries [2].

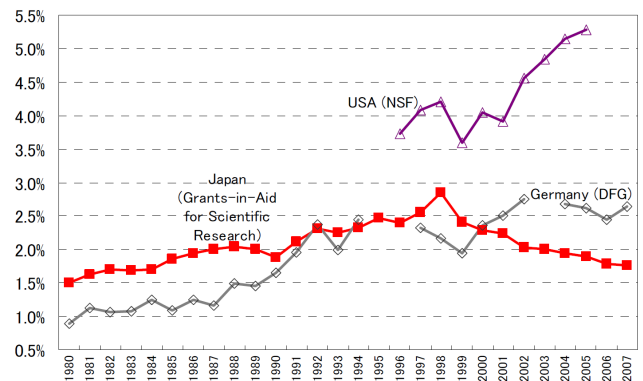


Figure 5: **Mathematics research funding as a percentage of the overall research funding in major countries** (prepared from the same sources as Figure 4)

Japan lacks national programs focusing on encouraging mathematics research. On the other hand, in the USA, mathematics research is carried out not only with NSF funding but also in the form of grants or national programs sponsored by bodies such as the Department of Energy (DOE), National Institutes of Health (NIH), and Department of Defense (DOD) [3]. In Germany as well, in addition to DFG grants, there is a national mathematics research program sponsored by BMBF that is in its fifth stage. There are active mathematics research consortium programs within EU frameworks as well [4].

Moreover, there appear to be only one or two centers of mathematics research in Japan. In contrast, since the 1990s, new mathematics research centers have been established in the USA, France, Germany, the UK, and Canada [3], and in China as well. Those in charge of the USA NSF's Division of Mathematical Sciences were aware that mathematics research centers were being established successively in many countries. The Japanese government lacks even a unit that specializes in mathematics research.

### 3. MISMATCHED SUPPLY AND DEMAND

In Japan, many students possess an outstanding expertise in mathematics, and there are also many students who enroll in universities and graduate in mathematics. Although the percentage of all students in Japan who graduate with degrees in mathematics is not as high as that in France (2.7%), Germany (1.8%), or the UK (1.4%), Japan stands at approximately the same level as the USA at 0.9% (2000-2004 annual average; see Figure 6) [4]. The percentage of master's degrees is much higher in Japan (1.5% in 2004) than in the USA (0.5%), and that of doctorates in Japan (1.2% in 2004) is close to that in the USA (1.7%).

The percentage of Japanese mathematics graduates increased during the first half of the 1990s (see Figure 6). The following factors are likely reasons for this phenomenon.

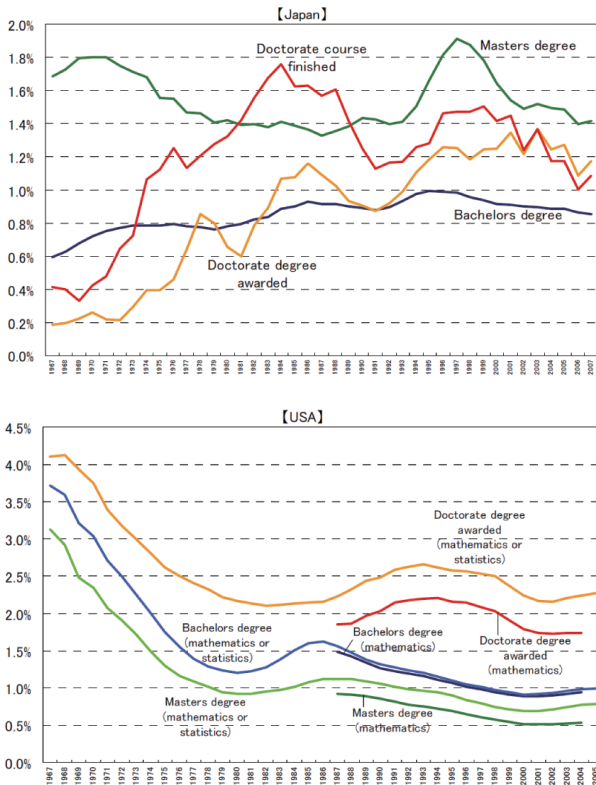


Figure 6: Percentage of all graduates majoring in mathematics in Japan and the USA (Three-year moving averages; this has been prepared based on the information obtained from “School Basic Survey” (MEXT, Japan) and the “Digest of Education Statistics” (National Center for Education Statistics, Department of Education, USA). “Doctorate degree awarded” implies those receiving the doctorate degree; and “Doctorate course finished,” those receiving the doctorate degree or those leaving school without completing degrees after their enrollment exceeds the maximum length.)

- 1) In 1991, the Japanese government eased regulations for national universities, leading to the breakup of the liberal arts departments. Many mathematics educators who had been involved within the liberal arts departments were shifted to other departments and were able to have their own research labs. This resulted in an increase in the number of slots available for graduate students in mathematics.
- 2) With the collapse of Japan’s bubble economy, departments related to research and technical occupations that were considered to be recession proof gained popularity among students.
- 3) The Japanese mathematician Shigefumi Mori won the 1990 Fields Medal, thus increasing the interest in mathematics in Japanese society.

Since the absolute number of Japanese doctoral graduates is small, most changes are minute; however, since 2003, the percentage for “Doctorate degree awarded” has been higher than that for “Doctorate course finished” (see

Figure 6). MEXT’s School Basic Survey apparently does not include doctorates, by thesis only (peculiar to Japan). This may indicate that in Japan, it has become easier to obtain a doctorate in mathematics than in other fields.

In Japan, the percentage of mathematics doctorate recipients who find employment during their first year after graduation is falling (see Figure 7). After reaching 90% in the early 1970s, the employment rate has declined steadily, falling below the average for all fields (60%) around 1980; presently, it is about 50%. Underlying this miserable situation is the fact that the number of mathematics doctoral graduates increased greatly in 1990’s, nevertheless, the majority of Japan’s university mathematics education remains oriented toward educating pure mathematicians for whom there are few employment opportunities. Some students may perceive this as highly disadvantageous for their careers. A survey of the participants of the preliminaries of the International Mathematical Olympiad revealed that medicine was presently the most preferred profession among them [5].

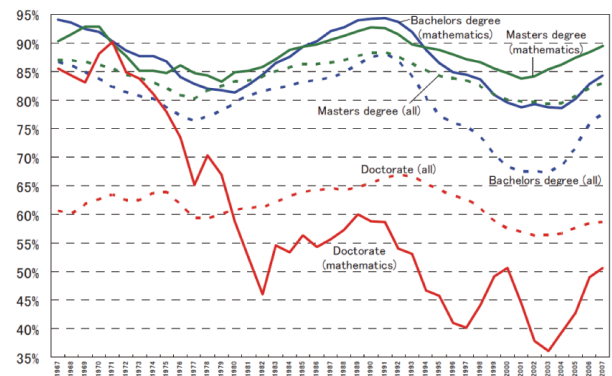


Figure 7: Percentage of all graduates in Japan who pursue further education or obtain immediate employment (Three-year moving averages; this has been prepared based on the information obtained from the School Basic Survey, MEXT, Japan.)

Meanwhile, the Japanese industry continues to crave for the power of contemporary mathematics. In a NISTEP survey of experts and researchers from all fields in Japan [2], 80% of the respondents replied that their own research was connected to mathematics, yet 70% responded that no member of their research team had a mathematics background (see Figures 8[b] and [c]). Moreover, 60% indicated that rival research teams in Europe and the USA included someone with a mathematics background, 60% said that there were certain themes in their research to which they hoped mathematics could contribute, and 70% indicated that their teams would require someone with a mathematics background in the future (see Figures 8[b] and [c]). Furthermore, Japanese researchers in the industry and other fields have expressed high expectations regarding contemporary mathematics from the results of workshops and symposiums as well [6], [7].

However, some Japanese mathematics researchers seem to consider mathematical theories in other fields as being

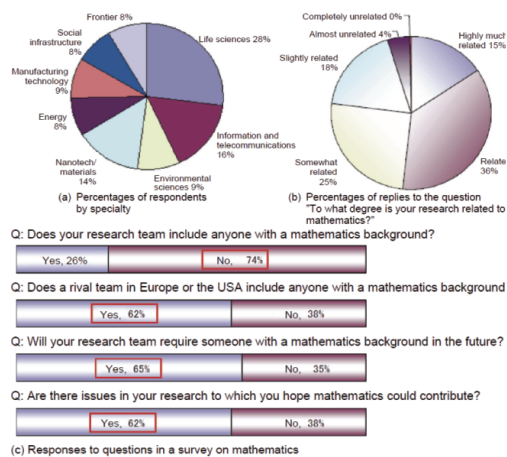


Figure 8: Results of a survey on mathematics (prepared based on the information obtained from NISTEP Policy Study No.12)

mere ornamentation. In the world of Japanese mathematics research, there continue to exist structures that can constrain the curiosity of researchers in the utilization of mathematics in applied mathematics and other fields. Meanwhile, even though researchers in the industry and other fields in Japan seek contributions from mathematics, there are common tendencies to view mathematics in practical terms of what use it can be of at present and to refrain from contemporary mathematics as a result of viewing it as being “too difficult.”

#### 4. RESEARCH ACTIVITY FROM THE PERSPECTIVE OF THE FIELD OF MATHEMATICS

The author examined the areas of mathematics research in major countries using the Thomson Scientific SCI database on research papers. The database employs two classification methods by assigning each academic journal to a single field, including mathematics as one of 22 fields, and by assigning them to any of the 190 areas (the number may vary by year), with multiple areas permitted. In the former classification system, mathematics is regarded as one subject area, whereas in the latter it is classified into three different areas: mathematics (similar to the concept of pure mathematics), applied mathematics, and probability and statistics. Examining the contributions to the field of mathematics (one of the 22 fields) through these areas from the average annual number of journals and research papers published during the period 1999–2003, on a worldwide average, mathematics accounts for approximately 60%; applied mathematics, 30–40%; and probability and statistics, 10–20%.

A comparison of the percentages of the number of research papers published in the subject areas of mathematics, applied mathematics, and probability and statistics with the number of mathematics research papers published according to the method using 22 fields (see Figure 9) re-

veal that Japan is better in pure mathematics rather than applied mathematics and probability and statistics as compared to other countries. Japanese trends are similar to those of France. Countries strong in applied mathematics and probability and statistics include the USA, Germany, the UK, and China. China, in particular, accounts for a particularly high percentage in applied mathematics.

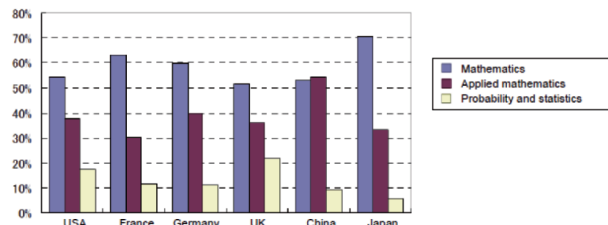


Figure 9: Papers published in the subject areas of mathematics (here, it implies a concept similar to pure mathematics), applied mathematics, and probability and statistics as a percentage of all mathematics research papers published (1999–2003 average). This has been compiled by NISTEP based on Thomson Scientific’s SCI (1982–2003). The total might exceed 100% because the subject areas of mathematics, applied mathematics, and probability and statistics might overlap. Since the percentage of bulletins in this database is probably relatively low, it could strongly reflect the characteristic of areas in mathematics such as applied mathematics (approximately 30% of the whole) and statistics (approximately 10%) that are less likely to appear in bulletins.

In addition, the author examined mathematics research areas from the perspective of the annual meetings that comprise the major activities of academic societies. The Mathematical Society of Japan holds two annual meetings (a spring annual meeting and an autumn general conference). The annual meeting generally has 11 permanent committees. The author examined the changes in the total presentation time and the percentages of the time allotted (see Figure 10).

As depicted in Figure 10, the total presentation time at the Mathematical Society of Japan grew markedly during the first half of the 1990s, reflecting the increase in the percentage of general presentations and the increase in the number of student members, as illustrated in Figure 6. The gap in the timing of the increases shown in Figures 6 and 10 is likely to have arisen from students presenting while they are still at school. In recent years, however, the total presentation time has been declining. This trend to some extent resembles the movement in mathematics research funding through Grants-in-Aid for Scientific Research (see Figure 4).

Observing the changes in the general presentations that account for more than 90% of the total presentation time and the content of special committee addresses (see Figure 11), the percentages accounted for by statistical mathematics and applied mathematics in particular have declined since the first half of the 1990s. Underlying this may be the past shift of mathematics educators from liberal arts departments to engineering departments and so on, and their subsequent estrangement from mathematics. Presentations by researchers in other fields, such as members of the Japan Society for Industrial and Applied Mathematics, are organized as “specially planned addresses”; however,

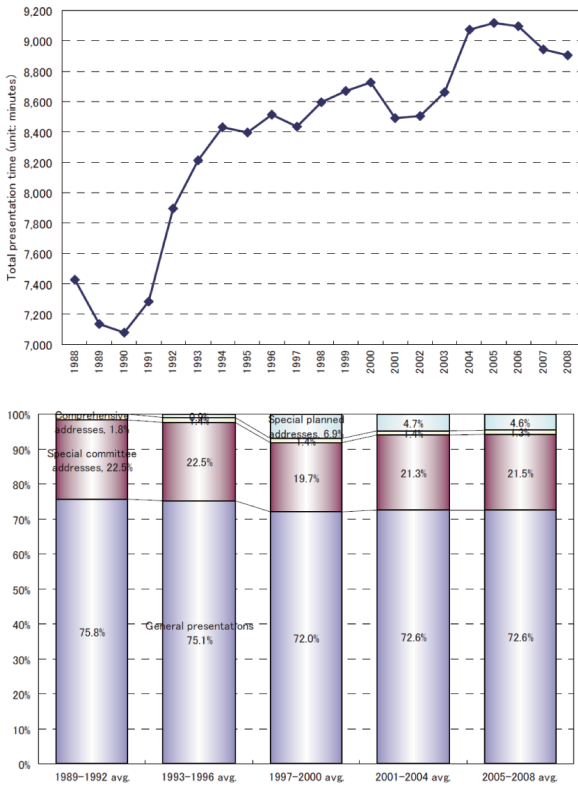


Figure 10: Total presentation time and percentages thereof in the two yearly meetings of the Mathematical Society of Japan (The figure on the left presents the three-year moving averages. The table has been prepared based on the information obtained from the programs of the Mathematical Society of Japan's annual meeting (March) and the autumn general conference(September). General presentations are requested by researchers; these are ordinary research presentations lasting 10-15 minutes. Other types of addresses are by invitation and last approximately one hour.)

their percentage with respect to the total presentation time is decreasing (see Figure 10).

In contrast, the American Mathematical Society (AMS) holds its national meetings in conjunction with the Society for Industrial and Applied Mathematics (SIAM), the Mathematical Association of America (MAA), the Association for Symbolic Logic (ASL), the Mathematicians and Education Reform (MER) Forum, and the Association for Women in Mathematics (AWM). The structure of these national meetings differs from that found in Japan, with the subject areas covered changing annually rather than being fixed. This author examined the total presentation time in the sessions sponsored by the AMS (see Figure 12). As illustrated in Figure 12, the total presentation time in the AMS has been increasing.

In light of the fact that the AMS with about 30,000 members has roughly six times the membership of the Mathematical Society of Japan with its approximate membership size of 5,000, the Mathematical Society of Japan is doing well with approximately 8,000 total presentation minutes (see Figure 10) as compared to the approximately 25,000 minutes of the AMS (see Figure 12). The trend over the last 20 years or so, however, shows that the Mathematical Society of Japan's total presentation time has increased by

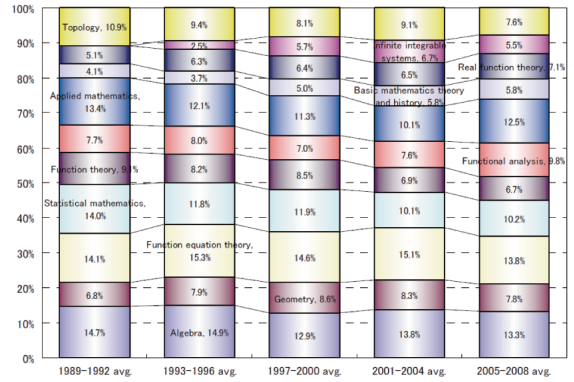


Figure 11: Breakdown of the general presentation and special committee addresses at the annual meeting and annual conference of the Mathematical Society of Japan (This has been prepared based on the information obtained from the programs of the Mathematical Society of Japan's annual meeting (March) and the autumn general conference (September). The "Infinite integrable systems" committee was introduced after the 1995 general conference.)

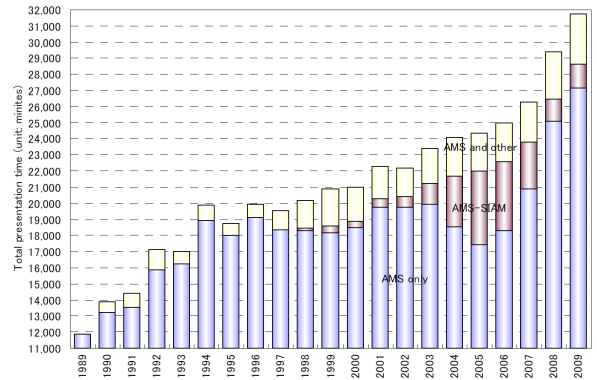


Figure 12: The total presentation time in sessions sponsored by the AMS (Three-year moving averages. This has been prepared based on the information obtained from the AMS's national meeting (January) programs)

10-20%, whereas that of the AMS increased by about twice as much.

Japanese mathematics research can no longer maintain the status quo in terms of Grants-in-Aid for Scientific Research (see Figures 4 and 5) and the total presentation time at mathematics societies (see Figure 10). Meanwhile, judging from research paper databases (see Figure 9) and the total presentation time at academic conferences (see Figure 11), mathematics research at Japanese universities focuses on pure mathematics. This gives the impression that Japanese mathematics research is losing ground, with the exception of the core, pure mathematics.

### 5. A WARNING TO THE JAPANESE SCIENCE FRATERNITY AND THE STATUS OF MATHEMATICS RESEARCH IN JAPAN

As part of the preparation for the designation of the Third Science and Technology Basic Plan (2006-2010) by the Council for Science and Technology Policy (CSTP),

NISTEP has been conducting a study evaluating the achievements of the Second Science and Technology Basic Plan (2001-2005) since 2003. Amidst this, leading foreign researchers have warned that Japan's research lacks depth. In concrete terms, they indicated that Japanese research activities create few research developments or new concepts from new discoveries [8]. It is likely that underlying this criticism is the tendency of Japanese science and technology as a whole to be weak in mathematical approaches. Underlying the emphasis on the collaboration between mathematics research and other scientific fields and industrial technology and the promotion of mathematics research as a whole in Europe and the USA is an awareness that the neglect of mathematical thought fundamental to science and industrial technology will lead Japan to lag behind in the world of leading-edge science.

During the past decade or so in Japan, various measures have been implemented. These include the formulation and implementation of the Science and Technology Basic Plan and the Science and Technology Basic Law upon which it is based, the establishment of the Council for Science and Technology Policy and the Ministry of Education, Culture, Sports, Science and Technology through the reorganization of national government ministries and agencies, industry-academia-government collaboration, and the shift to "National University Corporations". However, over a short period, these rapid reforms have resulted in unexpected side effects. For example, incentives from the authorities for mathematics research, which does not necessarily meet the goals of obtaining easily understood results and economic effects in a short period, are declining, and many universities have decreased their basic expenditures and the number of posts for mathematics instructors.

In addition, interviews with mathematics researchers uncovered the following structural issues.

- 1) Mathematics research requires a considerable amount of time for a researcher to engage in repeated thought and to compile the results in research papers; however, recently, in Japan, a considerable amount of paperwork has been taking up this time. In Japan, researchers themselves, rather than office staff, create the documents necessary for their evaluations and so on. Furthermore, the number of office staffs for Japanese mathematics departments, which was already small compared to that in the USA and other countries, is said to be decreasing.
- 2) Mathematics research requires venues where researchers can meet each other and exchange ideas as well as to meet the travel expenses to these venues. In Japan, however, even if outstanding researchers were likely to come, they would be unable to secure research space (which implies nothing more than a desk, a chair, and a white board). Japan appears to lack systems similar to those in the USA where research institutes assist researchers attending a conference by providing compensation for their travel ex-

penses.

- 3) Furthermore, because mathematics research papers rarely become obsolete, the papers themselves have a strong tendency of being test samples, and the quantity and quality of books and journals, too, are important. Moreover, there have traditionally been many types of mathematics journals; this has resulted in increasing costs as compared to other fields. Owing to the lack of funding for mathematics research in Japan, there are many cases of schemes such as multiple-university mathematics departments mutually supplementing each other's collections of mathematics research books and journals. However, with the reduction in the number of office staff members serving as librarians reducing, these collections are losing their functionality as libraries. It is becoming legally impossible to lend those books and journals to outside researchers.
- 4) In the case of Grants-in-Aid for Scientific Research, which account for a large portion of Japan's mathematics research funding, one cannot claim reimbursement for the cost of regular periodicals and journals that comprise a large part of the expenses of mathematics research. This is because one may not claim reimbursement for unpublished items at the time of application as necessary funds. In addition, mathematics research expenditures are lower because mathematics does not require expensive facilities and equipment unlike experimental science. Being unable to attract large amounts of external funding in this manner, mathematics naturally cannot meet the major overhead expenses to university administrations and thus carries little weight within university power structures.
- 5) Students who are unable to understand previous university-level lectures because their knowledge of mathematics acquired in high school is insufficient are now appearing in Japan. Therefore, university instructors have to conduct supplementary mathematics classes. However, in principle, Japanese university mathematics researchers are not permitted to employ other instructors to conduct lectures even if they maybe engaged in research projects at the university.

## 6. OUTLOOK

The Japanese government took immediate action after learning of the dismal state of mathematics research in Japan. This led to the historic inclusion of mathematics research in the Japanese government's medium- and long-term science and technology policy through the March 2006 Individual Fields Promotion Strategy (CSTP), the June 2006 Comprehensive Strategy for Creating Innovation (CSTP), and the June 2007 "Innovation 25" (Cabinet



decision). Furthermore, mathematics has been established as a research area in the JST's Precursor Research for Embryonic Science and Technology (PRESTO) which began in 2007 and Core Research for Evolutional Science and Technology (CREST) which continues to that in 2008, and as a target field in the MEXT's World Premier International Research Center Initiative.

Moreover, in response to our Policy Study No.12, the board of directors of the Mathematical Society of Japan indicated the society's awareness of the problems by issuing "A Proposal: Aiming to Improve Japan's Mathematics Ability" in September 2006. In addition, in February 2007, the Japan Federation of Statistical Science Associations issued "A Proposal for Promoting Statistical Science in Japan". In this manner, Japan's mathematics academia is regaining its effectiveness.

It is significant to note that the Japanese academia and the bureaucratic mechanisms have begun to regain their momentum. However, this is just the beginning. This alone, however, would be insufficient to resolve the problems in human-centered mathematics research described above. Along with additional study and policy-related initiatives from the Japanese government, it is time for Japan's mathematics researchers to demonstrate concrete plans and actions.

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