# Interfacing Education and Research with Mathematics for Industry: The Endeavor in Japan

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## 1 A Brief Historical Observation for Mathematics in Japan

### *1.1 Historical Comments*

Mathematics could be likened to an inextinguishable light that illuminates dark or unclear regions in our extremely sophisticated modern societies. Galileo Galilei once wrote that "nature is written in the language of mathematics," and needless to say, Descartes and Newton are also followed this tradition. Even now, mathematics continues to be the common language of science. Furthermore, even more than in the past, mathematics today plays the role of a compass by indicating the directions that research in science and technology should follow. Without mathematics, progress in all fields could only be made by blind exploration. In fact, we find mathematics at the heart of nearly all the advanced technologies that drive modern society, including information security, networks, medical technology such as CT scans and MRIs, control in chemical plants, blast furnaces, and nuclear reactors, the development of airplanes and automobiles, design in robotics, scheduling in transportation, logistics in industries, finance and insurance, risk management, searching for resources, weather and earthquake prediction, and entertainment, etc. No matter how different these fields are in appearance, many of them have identical structures in terms of their mathematics. This is frequently acknowledged as "the universality and the general applicability of mathematics." They are major characteristics of mathematics. For example, while it is a fact that the designs of CT scanners, MRI, and the control of blast furnaces for manufacturing iron each entail difficulties unique to their respective fields, mathematically, each involves the same activity—the solution of an inverse problem.

After the age of the revolutionary development of physics based on quantum mechanics and the theory of relativity in the first half of the twentieth century,

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mathematics has also gradually taken on a key role in the dramatic developments in biology, especially in molecular biology, in the latter half of the twentieth century to the present day. While existing mathematics was used in the initial creation of quantum mechanics, quantum mechanics in turn promoted the subsequent development of new mathematics. Even today, new research in mathematics that began because of a stimulus from research originating in physics, such as superstring theory and Witten's theories, is flourishing. In addition, in the biological sciences, mathematical methods have become important. Fundamental concepts are formalized as numerical models and biological phenomena are investigated through the analysis and simulation with such models. What is of note is that through its involvement in these areas of research, mathematics itself undergoes new development. In this way, scientific, technological and industrial applications have provided sustenance to mathematics. Mathematics is a marvelous, mysterious or somewhat unusual science without analogies in other fields of science. Without doubt, if anywhere in the universe there is a planet on which a sophisticated civilization has developed, mathematics will be playing a key role.

The traditional/historical relationship between mathematics and technology principally involved the physical and chemical sciences, and mechanics. After the Industrial Revolution in Europe, this relationship fostered both an enhanced understanding of nature and an increase in mathematical analysis research of scientific and technological problems. Among other things, this involved analysis of differential equations of Newton's mechanics. However, from the middle of the 1990s, when high capacity computing became available, modeling and simulation of the actual processes being studies became the focus. In this way, modern society gradually, and in recent years, dramatically, increased its dependence on mathematics. For example, mathematics, including statistics in addition to the mathematical analysis mentioned above, has become necessary in a greater variety of sciences and technologies. In addition to that the role of providing new techniques (design, construction, synthesis) for incorporation into a variety of problems, including, for instance, subject matter that does not necessarily have governing equations, has become stronger. The contributions of mathematical analysis, modeling and simulation to a wide range of sciences and technologies will become increasingly important in the future. In terms of its exploratory role, it is thought that mathematical analysis will become even more essential. In fact, the formulation of the theories of particle physics and the understanding of the cosmos, the role of mathematics in biological sciences and ecology, and in particular, in financial engineering, encryption and information security, computer graphics and the like, has already broadened the impact of mathematical analysis, modeling and simulation. For example, while the virtual reality in the movies "Jurassic Park", "Harry Potter" and the recent "Avatar" are heavily dependent on advanced mathematical algorithms related to data compression and image processing, they have abundant use of the synthesis aspects of mathematics. The functions of both the analysis and synthesis in a variety of studies are inseparable, and, in any cases, we can observe that the applications of mathematics have dramatically expanded into new unexpected fields. In July of 2008, in the Global Science Forum of the

OECD (Organization for Economic Co-operation and Development), a report entitled "Mathematics in Industry" was published that clarified how necessary mathematics is in the everyday activities of modern society (OECD). In spite of this, there is a major shortage of mathematicians and mathematical scientists capable of responding to this need. Indeed, this represents a challenge for a society heavily dependent on mathematics.

Since the ancient Greeks, mathematics has become one of the intellectual pinnacles of civilization. Motivated by curiosity and the history of their training, many mathematicians see their own research as a pure logic independent of the real world. However, reflecting on the history of mathematics, we understand how useful the discipline of mathematics has been for human beings even when separated from immediate applications. Examples include the use of non-Euclidian geometry, which was essential for Einstein's construction of the theory of relativity; the role of the factorization by prime numbers and the study of elliptical curves in Number theory, which plays a central role in information security; and Dr. Kiyoshi Ito (1915–2008) formulation of stochastic differential equations, which were the origin of the foundation of financial engineering. When Koch's snowflake curve was discovered, it was thought to describe only to "pathological" phenomena. However, this idea was refined into fractals, and now, as is widely known, fractals have significantly contributed to the development of computer graphics. Thus, even if they appear to be pure theory, all fields of mathematics always have important applications hidden therein. In addition, compared to studies that originally aim at application, once pure mathematics has been discovered to be useful the impact of the results of pure mathematics is something extraordinary (Related to this historical remarks, see also Wakeyama 2013).

## *1.2 Mathematics in Japan*

In this connection, in Japan, there are several misunderstandings and mistaken assumptions concerning mathematical studies. There are occasions in which mathematicians appear to be as if inhabitants from another planet. In the background, one can imagine that, in the early Meiji era in Japan, there were difficulties—limitations arising from geographical conditions—in transferring and developing involvement with the spectrum of Western mathematics, including the various aspects of applied mathematics. As a result, the European traditions of applied mathematics, directed toward solving practical problems in society, did not come to Japan. In this situation, only limited fields of application were developed. The reason for this was that the centers for applied research in Europe were mainly located at technical universities. Because applied research was not relevant to Japan's situation, a role for applied mathematics was not envisaged. In other words, we can infer that systematically importing applied mathematics was much more difficult than importing pure mathematics, which did not require the infrastructure associated with the mathematical analysis of practical problems. Ultimately, the pure mathematics of Göttingen in Germany, which was said to have been at the highest level in the world, was first chosen for dissemination during the opening up of the country at the end of the Meiji Era. But having said this, fortunately, the import of this pure mathematics suited the mental tenor of Japan, and was welcome. Actually, even leaving aside the use of mathematical puns by the oldest Japanese poets (the Manyo-shuu anthology) who enjoyed word play, Japan had a social worldview in which mathematics was valued (including a game element), as can be seen with the spread of calculation using the abacus (e.g. accounting), the mathematical votive tablets featuring mathematical puzzles mainly in Euclidean geometry offered to the Shinto Shrines and Buddhist Temples (Sangaku) and the like. In addition, as represented by Takakazu Seki (1642–1708), the rise of Japanese-style mathematics (Wasan) in the late 17th century during the Edo Era, which had reached a world-class level, is even now well known internationally. Naturally, in Japan, it can be said that in terms of world history, during the peaceful Edo Era, the need for mathematical studies related, for example, to the calculation of the trajectories for cannons, was very limited. In addition, the ancient national character, that enthusiastically imported leading-edge sciences and technologies and that furthermore spared no effort in perfecting them, also played a role. Under the prevailing stable political conditions, a very unique culture developed. Consequently, after the opening up of Japan during the Meiji era, its mathematical capabilities enabled a rapid absorption of the imported Western pure mathematics traditions. In addition, this was the source of the energy that allowed globally advanced centers to be established at a surprising speed in pure mathematical studies that focused on algebra, and in particular, number theory, as represented by the completion of class field theory by Dr. Teiji Takagi (1875–1960). In addition, many remarkable results were attained in various fields of pure mathematics that brought recognition by the international research community.

## *1.3 Applied and Industrial Mathematics in Japan*

At the same time, the high level of mathematical applications in leading fields of engineering, such as mechanical engineering, electrical engineering, and precision machinery engineering, which supported and produced Japan's period of advanced growth, should be single out for special mention. The difficulty with importing applied mathematics along with pure mathematics in the Meiji Era has already been described above. Accompanying the transfer of leading-edge technology at the time, the sprouts of applied mathematics were also being transferred (perhaps surreptitiously) to newly established university engineering schools. There it was subsequently cultivated and, helped by Japan's sophisticated pure mathematical tradition, applied mathematics took root in engineering. In fact, one can immediately find the many high level technologies in the old Japanese history, e.g., in civil engineering (Japan is indeed a country of the mountains and rivers), architecture such as Horyuji Temple, the oldest standing wooden architectures in the world which was built in the beginning of the seventh century, etc. Behind these, it is no doubt about the existence of developed practical/non-abstract arithmetic computation and measurement techniques.

Furthermore, in the latter half of the Showa Era, when the performance of computers was still not very high, in order to use computers and obtain meaningful results, first a problem had to be formulated mathematically and numerically. Researchers in mechanical and electrical engineering at the time were probably not consciously aiming to be applied mathematicians, but essentially they drew on high level mathematics, and when necessary, developed new mathematical tools/techniques by themselves, and then carried out research on the resulting topics. Indeed, similar to theoretical physicists, it is thought that because there were many mathematically talented engineers, they could also respond to the great needs of industry, which had provided explosive economic growth. The situation described above is one reason that Japan is unusual in thinking that "mathematics" is pure mathematics. However, ironically, entering the era of fast and inexpensive high performance computing, for engineers in particular, the applied part of mathematics has been placed, through the extensive use of general-purpose software, in a black box. As a result, although there are still superior "applied mathematicians" involved, the emphasis on the mathematics in engineering (the principal object of which is making things) has rather declined. It is worrisome that most general-purpose software is imported from abroad. This general-purpose software is used, for example, for motion capture machines, which are indispensible for making, among other things, movies, animation, and games. Fortunately, in computer science and informatics (which, in Japan, is frequently situated in engineering department due to its relationship with the development of hardware as a subject in electronics), mathematics is even more widely and fundamentally considered to be an important subject of research.

Even in mathematics, the pronounced tendency to create a division between pure and applied mathematics appears in both the East and the West. Because of their different roles, the distinction between the two may be convenient if used appropriately. We can, however, broadly perceive that this distinction, which places a wall between mathematicians is diminishing. Consider Nineteenth Century mathematicians. Great mathematicians such as Gauss, Fourier, Cauchy, Riemann, who will continue to influence present and future mathematicians, did not stop at research in pure mathematics. For example, the "Riemann hypothesis" was conceived 151 years ago and is the greatest unsolved problem in pure mathematics, still defying the efforts of mathematicians. But its results are also a focus of attention from the point of view of information security and research on cryptography. This is because this hypothesis makes clear the ultimate form of the distribution of prime numbers. Thus, in cryptography research, there is an interest in mathematics that transcends boundaries between pure and applied mathematics. In fact, we should remember that the outcome and attraction of applied mathematics is that it frequently stimulates the desire in pure mathematicians for pure mathematical studies which do not aim at application.

# 2 Education and Research Hub for Mathematics for Industry

## *2.1 Mathematics for Industry*

The phrase "Mathematics-for-Industry (MI)" denotes a new research field in mathematics that will serve as a foundation for creating future technologies. This phrase/notion was born from the integration and reorganization of pure and applied mathematics into a fluid and versatile form capable of responding to the needs of industrial technologies.

## *2.2 Graduate School of Mathematics, Kyushu University*

Going beyond the wall between pure and applied mathematics, and fully expressing the freedom and variety that mathematics possesses for fostering young researchers, the Graduate School of Mathematics, Kyushu University has initiated a twenty-first Century Center of Excellence Program called "Development of Dynamic Mathematics with High Functionality" (FY2003-2007) which was promoted by the Ministry of Education, Culture, Sports, Science, and Technology (MEXT). The same graduate school and Faculty of Mathematics have made constant pioneering efforts, leading the whole of Japan, in developing an environment that promotes integrative research between mathematics and other fields, and fosters cooperative research between mathematics researchers and industry. These efforts dedicated to organizational reformulation have gained the support of the MEXT Program for Enhancing Systematic Education in Graduate Schools, "Raising Doctorates and New Masters in Mathematics Required by Industrial Technology" (FY2007-2009), the Global Center of Excellence (Global COE) Program "Education & Research Hub for Mathematics-for-Industry" (FY2008-2012 GCOE), and a Special Fund by MEXT "Project on Graduate Education in Mathematics for Globalization" (FY2010-2015). Through the activities associated with these programs, we find that the acceptance of long-term internships for students in the doctoral program is spreading to a variety of industries in Japan and abroad. A new career path is being opened up for the mathematics doctorates, and in addition, and cooperative research prompted by this has also commenced. The significance of such activities is spreading to other universities, and the attitude of the faculty members is changing along with the graduate students majoring in mathematics.

### 2.3 Background About the Programs: From the Report by Nistep

Advances in mathematics are essential for future technologies, and many companies feel a lack of personnel with advanced mathematical skills and expertise. In fact, according to the report by the National Institute of Science and Technology Policy (NISTEP) of MEXT in 2006, the percentage of people in research and development in the private sector in Japan, who possess mathematical background, is planned to be around 65 %, which is the same as that of advanced countries of Europe and North America. The current percentage in Japan is only 26 %. As Japan aims for sustainable development in science and technology, there is an urgent demand to train people to fill this almost 40 % gap (see Hosotsubo 2009 and references therein).

### 2.4 Various Activities

**a) Long-term Internship for PhD Students in Mathematics:** The Graduate School of Mathematics, Kyushu University, introduced in 2006 a program "Long-term internship for PhD students in industries" as part of the curriculum for the new doctoral course Functional Mathematics. This long-term internship provides a joint research opportunity for the students for 3 months or more at industrial R&D laboratories. About 45 students have already completed the program. The long-term internships have turned out to be far more successful than expected. They have not only attracted attention from domestic universities but also from people working in industry. Some students obtained patents, papers, and even initiated new collaborative researches opportunities between enterprises and faculty members. After getting PhD degrees in Mathematics, almost 15 % have obtained positions in academia, 60 % in industry, and the remaining have post-doc positions in several universities and public research institutes.

A: To perform a necessary improvement continuously for this program, we have been trying to observe and understand the real situation before and after the students spent months at the industry. As a result of the observations, the points to assist the students are:

Change their current views

1. to recognize the usefulness of mathematics in industry and social life
2. to recognize the integrated power of the company to tackle a problem
3. to have responsibility and to experience the joy of achievement
4. to recognize the usefulness of logical thinking intrinsic to mathematicians
5. to recognize the power of math graduates
6. to experience a regular daily life

Develop the required skills or recognitions

1. the importance of skill of computer programs
2. the necessity of communication ability
3. the shortage of knowledge of physics, etc.

B: Companies where we have sent PhD students are:

Hitachi Ltd., NTT (Nippon Telegraph and Telephone Corp.), IBM Japan, Toshiba Corp., Ube Industries Ltd., DIC Corp., Mitsui Engineering & Shipbuilding Co. Ltd., Fujitsu Ltd., Zetta Tech. Inc., Panasonic Corp., Nishinn Fire & Marine Insurance Co. Ltd., ING Insurance (the Netherlands), Nippon Steel Corp., Mazda Motor Corp., OLM Digital Inc., Nessan Heat Corp. (also, the National Institute of Communication Technology.)

C: Students' fields of specialization include:

Statistics, Fluid dynamics, Algebraic geometry, Number theory, Representation theory, Optimization theory, Nonlinear analysis (PDE), Theoretical computations and Computer algebra, Operator theory, Differential geometry, Topology, Combinatorics, Numerical Analysis, Game theory, Cryptography, Mathematical physics, Probability theory.

D: Research themes include:

Face recognition, Analysis of electromagnetic fields, Information processing of visually movements, Cryptography, Fluid analysis, Information processing, Fluid analysis in the chemical device, Tree structure data analysis, Liquid crystal simulation, Optimization, Electronics system modeling, Risk management, Date analysis, Time series analysis (Fig. 1), Processor analysis, Data compression, Video encoding, Image compression, Data processing, Codes research by using Chaos, Machine learning, 3-dim heating control.

**b) Master of Mathematics Administration (MMA):** The MMA program is a mathematics version of the MBA program and designed to cultivate (Master course) graduate students to be experts in coordinating research and development activities, that is, building bridges between R&D and planning sections in industry, based on mathematics from broad and long-term perspectives. It is also expected that graduates under this program will make a significant contribution as MI research personnel along with traditional Master's in mathematics.

**c) Study Group Workshops:** From 2010, a short-term camp-style "Study Group" that tackles unsolved problems that industries are faced with has been initiated on a nationwide scale. This is the first full-scale Study Group Workshop in Japan organized jointly with the Global COE program "The Research and Training Center for New Development in Mathematics" in Graduate School of Mathematical Science, the University Tokyo. More than 120 people joined this one-week workshop in 2010. The list of companies and their proposed themes in 2010 were:

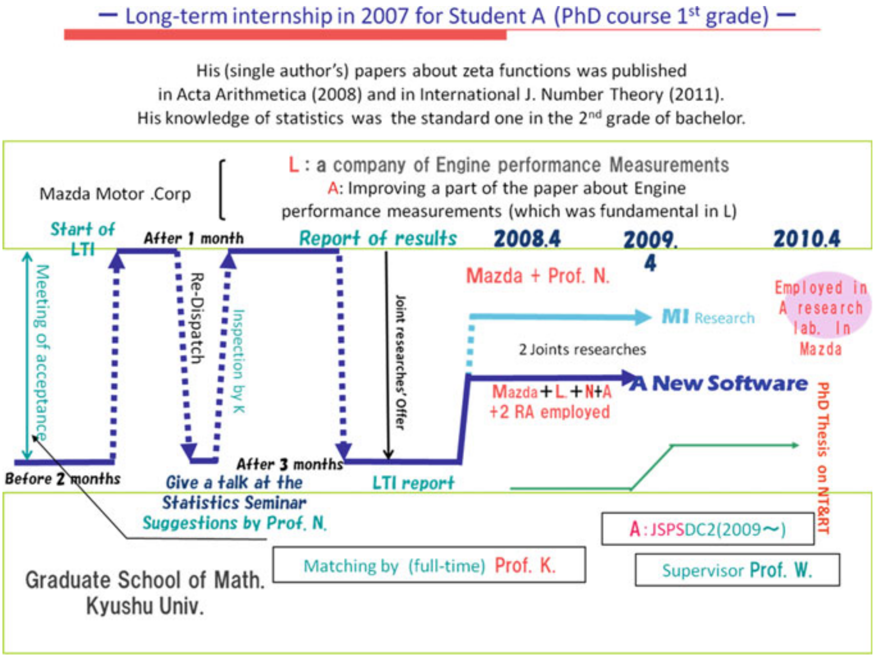


**Fig. 1** Internship in Mazda

- Hitachi Ltd.: Validity of lattice reduction algorithms for CVP
- Toshiba Corp.: The section finding problem and algebraic surface cryptosystems
- OLM Digital Inc.: Interactive editing of light and shade for 3DCG
- WETA Digital: Open problems in visual effects
- Nippon Steel Corp.: Inverse problem from multi-scale viewpoint utilizing a combination of stochastic, analytic, and geometric modeling
- Kao Corp.: The problem of spread of communication on the net space
- Takeda Pharmaceutical Company, Ltd.: (1) Development of prediction method for solubility of crystalline compound via 2D-structure, (2) Development of structural calculation system associated with chemist' sense, (3) Development of practical algorithm to generate theoretically possible structures under restriction conditions

Also, two mathematicians from Indian Institute of Technology and CSIRO in Australia have proposed, respectively, the following problems.

- Challenges in provable security of cryptosystems
- Analysis and utilization of spectroscopic data

This year in August, at the Study Group Workshop organized jointly also by Kyushu University and the University of Tokyo, we will have the theme-presentations from NTT, NEC Corp., Mitsubishi Chemical Corp., OLM Digital Inc., Fujitsu Ltd., Fujitsu Lab. Ltd., Nippon Steel Corp., etc.

**d) Forum "Math-for-Industry":** Every year we hold this forum. The last two were as follows:

**2009: Casimir Force, Casimir Operators and the Riemann Hypothesis—Mathematics for Innovation in Industry and Science—November 2009, Nishijin Plaza, Kyushu University**

The year 2009 marks the 100th birthday of Casimir and the 150th birthday of the Riemann hypothesis. Actually, the chapter in which Riemann proposed the hypothesis was published in November 1859. It was also the year when he was appointed as full-professor at Göttingen. Casimir, known for the Casimir force in physics and Casimir operators in mathematics, was director of Royal Philips research for a long time in his career. Casimir got his PhD in November 1931 at Leiden University and the named operators appeared in his thesis. He is remembered for his outspoken opinion on the importance of fundamental science for industry. There is a nice connection between Casimir and Riemann. The Casimir force was first proven to exist theoretically, using the analytic continuation of the Riemann zeta function. Recently, the force was measured experimentally.

**2010: Information security, visualization, and inverse problems, on the basis of optimization techniques, October 2010, Hilton Fukuoka, Sea Hawk**

At the forum, we will mutually relate and discuss the three topics: the information security, visualization, inverse problems, on the basis of optimization techniques, and at the succeeding 5-days study group, after proposals of concrete real problems from companies and public institutes, we will work toward solutions by divided groups of participants.

The Forum "Math-for-Industry" 2011 will be held in the East–West Center, University of Hawaii at Manoa (24–28 October) under the title:

**2011: "TSUNAMI—Mathematical Modelling" Using Mathematics for Natural Disaster Prediction, Recovery and Provision for the Future**

Our objective is to consider what help can mathematics provide against natural disasters; to understand their fundamental mechanisms, to increase the accuracy of predictions, to minimize damages and risks, to establish more robust and efficient social systems for recovery, and so on. Thus, the lecture theme includes the following research topics: tsunami, earthquake, environmental pollutions, logistics, optimization, control theory, statistics and data analysis, information security, CG visualization, PDE, inverse problems, numerical analysis, fluid dynamics, integrable systems (solitons), geometry and topology, etc.

**e) Journal of Math-for-Industry:** We launched an electronic journal (but have published a hard copy once a year), the Journal of Math-for-Industry (JMI), which is published at the institutional repositories. This journal JMI is dedicated to the broadening of the horizons of Mathematics for Industry and swiftly and internationally publicizes achievements in education and research on MI. JMI presents original research papers and survey papers with original view-points in all scientific disciplines in which the mathematics or that in industry plays a basic role. Articles by scientists in a variety of interdisciplinary areas are published.

Research areas include significant applications of mathematics to industry, including feedback from industry to mathematics, new developments in Mathematics for Industry, and new developments in mathematics.

## 3 Mext's 2009 Project "Investigation and Estimation of Promotion of Cooperation of Mathematics and Mathematical Science with Other Fields"

This was the Investigation project commissioned by MEXT in 2009 and promoted by the group consisting of Kyushu University (the representative institute), the University of Tokyo, Mathematical Society of Japan and Nippon Steel Company. In this project, we investigated and estimated the activities of mathematics and mathematical science, and those of their cooperation with the other fields that had been implemented in Japan, and thereby gained ideas for making a proposal to the Japanese government for promoting mathematics and for strengthening cooperation with various fields surrounding mathematics, which will achieve creation of new values and promote innovations. We made the final proposal in the end of March 2010 as follows:

After the investigation, we have submitted the policy consisting of the following five proposals:

1. Support an establishment of hub (governmental funds),
2. Establish a section for the promotion of mathematics and mathematical science in the government (so far, no such section has existed in the government),
3. Renew or continue to the JST (Japan Science and Technology Agency) program "Alliance for Breakthrough between Mathematics and Sciences", which is currently being promoted, for mathematics with other discipline and technology,
4. Put the clear description for promoting mathematics/mathematical science at the governmental important document such as "the fourth governmental science and technology master plan",
5. Establish an official committee and organization for promoting mathematics and the applications in a flame in the government.

It was conceptually and in principle accepted and the government would make a policy to promote researches in the field of mathematics and mathematical science in the following few years. In fact, the results we have now are; 2. the establishment of the "Mathematics Innovation Unit" (MIU) in MEXT, 4. in "the fourth governmental science and technology master plan" of the Prime Minister's Council of Science and Technology Policy (CSTP), the "mathematical sciences" are specifically mentioned for the first time, and 5. a new committee "Committee of Mathematics Innovation" has been established under the Council for Science and Technology in the government, while 1. has not been accomplished although MIU has been trying but looks pretty difficult especially in the current situation in

Japan and 3. is under discussing. Actually, this year the government would provide small funds for holding such workshops. There will be hence held 23 workshops jointly organized by MEXT and several groups of mathematicians or institutes of mathematics in the academic year.

## 4 Foundation of the Research and Education Hub "Institute of Mathematics for Industry" in Kyushu University

The origin of the idea for establishing this Institute can be traced back to the establishment of the Mathematics Research Center for Industrial Technology (MRIT, April, 2007–March, 2011) and subsequently, a concrete concept was delineated when Kyushu University applied to the Global COE Program. During the University's participation in the Global COE Program project, in order to organize PhD education and research in MI in a more systematic manner, the Faculty of Mathematics was reorganized, with strengthening of the function of the MRIT, to found the IMI. About one-third of the members of the old Faculty of Mathematics are participating in the Institute.

The Institute of Mathematics for Industry (IMI) has been established in April 2011 as the university's fifth research institute. IMI is a deliberately planned offshoot of the Global COE Program "Education and Research Hub for Mathematics-for-Industry." From its birth in 1939, the Department of Mathematics in the Faculty of Science has enjoyed a long tradition of respect for striking a harmonious balance between pure and applied mathematics. This balance serves as the framework of designing IMI.

The basic activity of IMI is to promote industrial mathematics on and for the basis of various mathematics researches and to grow human resources in this field. By Mathematics for Industry we mean a new field of research for creating industrial mathematics of the future. The history of the development of mathematics has led us to the belief that an essential idea will someday find its utility. The history shows, on the other hand, examples of the inability of research to respond to the serious requests from the society even in the cases of actual demand. For that reason, with a focus on mathematics, IMI aims to cooperate more closely with industry through joint research and to advance, over the pure–applied barrier, to a wider range of mathematics in amalgamated form. IMI focuses on basic research while respecting its contact with modern society. IMI also needs to focus on the facts like, for example, the great pioneers of the nineteenth century who combined theoretical research and numerical calculations. While focusing on both theoretical and computational/experimental research, IMI will incorporate deterministic considerations, and statistical and probabilistic methods to continually promote research from a broad outlook. In addition, IMI will step-by-step establish itself as a center of interactive cooperation between mathematics and various industry and scientific fields. Internationally, IMI will forge industry–mathematics collaboration in the

Pacific and East Asia regions as a global partner in activities associated with Mathematics for Industry.

The activities of IMI include (1) promoting collaboration with industry (2) organizing workshops and study groups (3) holding seminars for industry-academia partnerships and mathematical tutorials, and (4) raising PhDs and future human resources in Real World with mathematical background. The institute has 25 regular faculty members and consists of three main divisions; Advanced Mathematics Technology, Applied Mathematics, and Fundamental Mathematics. Beside, in order to efficiently promote the above projects/activities, the Visiting Scholars Division, and Partnership Promotion and Technical Consultation Room have been established.

Kyushu University has instituted Graduate School/Graduate Faculty System. According to the rule of this system, university faculty members, in principle, belong to a Graduate Faculty or a Research Institute. A Graduate School is an educational organization (education body) of a graduate school studies. IMI and the Faculty of Mathematics are the partner bodies responsible for the Graduate School of Mathematics.

Today, the importance of mathematics is better recognized than ever even in Japan, with accumulation of evidences that mathematics contributes directly and crucially to deepen things and to solve problems in the society. As a consequence, the roles of experts dedicated to mathematics are growing for the development of the society. The day is not far off when mathematicians—the describers of scientific foundations—will be the navigators for the real world and industrial technology. While aiming to train researchers for positions at universities, research institutes, and in industry, IMI will make every effort to develop excellent professionals who can meet the needs of society. IMI's mission is to become a center on the cutting edge of mathematics in the real world and world of science.

In the field of mathematics, IMI is the third research institute established in Japan after the Institute of Statistical Mathematics and the Research Institute of Mathematical Science (RIMS), Kyoto University, but has a distinctive feature. As such, the birth of IMI marks the formation of a unique international institute. Actually, this Institute aims to form a world-wide preeminent research center for industrial mathematics based on the idea of MI. Furthermore, by maintaining and developing cooperative relations with the Faculty of Mathematics in Kyushu University, we shall achieve a global educational research center for mathematics that will represent Japan (Fig. 2).

Mathematical Research

- There are no limits,
- A gradual broadening will be seen in the "universe of the real world",
- The ordered sequence, say the pure and then followed by the applied, in the progress and deepening of mathematics is not necessarily fixed, and
- Fundamental research in mathematics having the present progressive form turns out to be the future industrial mathematics.

The mathematical research area viewed from such a perspective is the Mathematics for Industry.

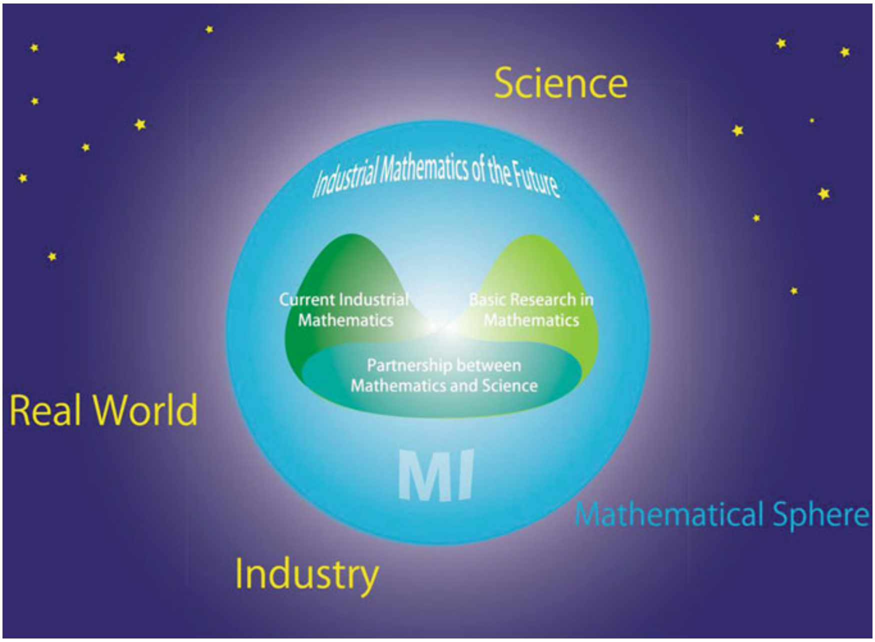


**Fig. 2** The results of basic research or pure mathematics, though not in a form that can be imagined or predicted in advance, will contribute in the future to the development of many sciences and will be useful for resolving the problems of the real world. In addition, new mathematics will be born and a deepening of mathematics will be generated by the applied research in mathematics that is developed to solve real-world problems. This figure shows

## 5 Asia-Pacific Consortium of Mathematics for Industry

We will inaugurate the Asia-Pacific Consortium of Mathematics for Industry (APCMI) in the East Asian and Pacific areas in October 2011, which has been planned from the fall of 2009. The APCMI aims to create an international stronger platform for the worldwide developed activities of the mathematics for industry.

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## References

M. Hosotsubo (2009). Survey analysis of Japanese mathematics research. *Journal of Mathematics-for-Industry, 1*(A-10), 73–80.

M. Wakeyama (2013). Importance and unpredictable effectiveness of mathematics in the real world and for industry. *What mathematics can do for you*, Giga, Yoshikazu, kobayashi & Toshiyuki (Eds.), Springer, 101–121.

http://gcoe-mi.jp/english/.

http://www.oecd.org/document/8/0,3746,en_2649_34319_42626653_1_1_1_1,00.html.