Feature Background behind the Emergence of Nobel Prize Winners - Aiming at Continuing to Produce Nobel Prize Winners from Japan

Japanese won a Nobel Prize in 2015, just as they did in 2014. This remarkable accomplishment thrilled the whole of Japan. On October 5, it was announced that the Nobel Prize in Physiology or Medicine would be awarded to Dr. Satoshi Omura, Distinguished Emeritus Professor of Kitasato University, who developed medicine that cured hundreds of millions of people who suffered from infectious diseases. The following day, October 6, the Nobel Prize in Physics was awarded to Dr. Takaaki Kajita, Director of the Institute for Cosmic Ray Research, University of Tokyo, who proved that that neutrinos known by physicists as ghost particles actually have mass.

Dr. Omura shakes hands with Dr. Campbell at the press conference.
Source: The Kitasato Institute

This feature gives an overview of research that earned Nobel Prizes in 2015 and considers how researches by previous Japanese Nobel Prize Winners were involved in these achievements. The above will give suggestions for the formulation of policies for science and technology innovation for the future of Japan[1].

Dr. Kajita is awarded the Nobel Prize.
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1 Winning the 2015 Nobel Prize, and the Key to That Achievement

(1) Outline of the research that was awarded the 2015 Nobel Prize

In 2015, the Nobel Prize in Physiology or Medicine and the Nobel Prize in Physics were awarded to researchers in Japan. Winning these awards is Japan's specialty. Dr. Omura, who won the Nobel Prize in Physiology or Medicine, follows in the footsteps of Dr. Shibasaburo Kitasato and Dr. Hideyo Noguchi, who left great marks on infectious disease research. The research of Dr. Kajita, who won the Nobel Prize in Physics, was an extension of work by Dr. Masatoshi Koshiba (Honorable Emeritus Professor, University of Tokyo), who won the Nobel Prize in Physics in 2002. Dr. Kajita became the seventh Japanese particle physicist to be honored with this prize.

① The research achievements of Dr. Omura

Ivermectin, a therapeutic agent, is an achievement of Dr. Omura and Dr. William C. Campbell, a Research Fellow Emeritus at Drew University. It is a "magic bullet" for treating two parasitic diseases:

1 In writing this feature, we enlisted the cooperation of the National Institute of Science and Technology Policy (NISTEP) and the Science, Technology and Innovation Policy Research Center (SciREX Center) at the National Graduate Institute for Policy Studies. They helped to arrange interviews, collect background on the winners and the like. (In addition, we were funded by a Grant-in-Aid for Scientific Research (C) for *Empirical Research through Analysis of the Nobel Prizes: Relationship between Knowledge Creation Process and Research Promotion Policy* (Grant #24501092; research director: Dr. Shinichi Akaike)).

river blindness and lymphatic filariasis. These have afflicted people in Africa, Central and South America for many years. River blindness is an infectious disease caused by a nematode transmitted by black flies. The disease causes visual impairment from retinal inflammation. In extreme cases, blindness occurs. Lymphatic filariasis is caused by a nematode transmitted by mosquitoes. The disease causes chronic swelling that persists over the lifetime of the infected person. Karolinska Institute, which is the institute that awards the Nobel Prize in Physiology or Medicine, praised Dr. Omura's achievement, saying that "These two discoveries have provided humankind with powerful new means to combat these debilitating diseases that affect hundreds of millions of people annually. The consequences in terms of improved human health and reduced suffering are immeasurable."

Dr. Omura is welcomed by children who were saved from river blindness.
Source: Professor S. Omura, Kitasato University

In 1963, Dr. Omura was employed as an assistant at a laboratory of the University of Yamanashi. The lab's research related to the making of wine, a local specialty product. Wine is made by the alcoholic fermentation of microorganisms called yeasts. While working in that lab, Dr. Omura recognized the great potential of microorganisms. The research results of Dr. Omura that led to his Nobel Prize began when he first encountered those microorganisms at the University of Yamanashi.

After that, he moved to the Kitasato Institute. In 1971, he was invited as a visiting professor by Wesleyan University in the United States. Dr. Omura returned to Japan in 1973 because he was invited to serve as the Director of the Laboratory of Antibiotics at the Kitasato Institute. At that office, he worked energetically to investigate the anti-microbial activity of antibiotics created by microorganisms, many of which live in the soil. Dr. Omura and the personnel in his office always packed small plastic bags and a spoon when they commuted or traveled on business. They collected soil at various locations, separated the microorganisms from the soil, and investigated them for anti-microbial activity. Their research was conducted jointly with the pharmaceutical company Merck & Co., Inc. of Kenilworth, N.J., U.S.A. (called MSD in countries other than the U.S.A. and Canada; hereinafter: MSD). Professor Tishler of Wesleyan University, who mentored Dr. Omura while he was studying at Wesleyan, acted as a liaison between Dr. Omura and the company. With the assistance of Professor Tishler, who had directed an MSD laboratory, the Kitasato Institute, to which Dr. Omura belonged, was able to enter into a three-year contract under which the institute would receive $80,000 a year in funding from MSD. Thus, the institute acquired sufficient funds[1].

Then, in 1974, Dr. Omura found a previously unknown species of actinomycetes in a sample of microorganisms that lived in soil taken from near a golf course in Ito City, Shizuoka Prefecture. Dr. William C. Campbell, who conducted joint research with Dr. Omura, revealed that the species of actinomycetes produced a substance with anti-parasitic properties. A research group at MSD extracted and isolated that substance from the microorganism and named it avermectin. Avermectin was effective as an anti-parasitic agent. The research group then pursued chemicals that would be efficacious even in small

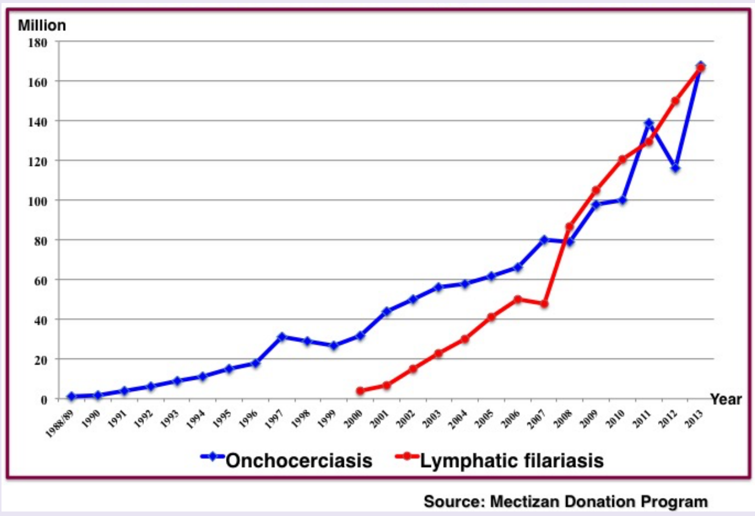
1 *A Chemist Defends 200 Million People from a Disease - Satoshi Omura* (in Japanese) (2012) written by Rensei Baba, published by Chuokoron Shinsha Inc.

amounts. They finally developed ivermectin by partially altering the molecular structure of avermectin, Ivermectin was shown to have a dramatic effect: 99.6% of parasites were removed from cattle that were subcutaneously injected with a single 200-microgram dose of ivermectin. In 1981, ivermectin was released by MSD as an anti-parasitic drug for livestock, under the trade name Ivomec.

Ivermectin was first used as an animal drug. MSD and the World Health Organization (WHO) began a joint investigation on its possible effectiveness against human diseases. Finally, they found it to be effective against a nematode that causes river blindness. In 1987, MSD obtained permission from the French government to use Mectizan (a medicine developed based on ivermectin) for the prevention and treatment of onchocerciasis (river blindness). From that year, MSD began to provide the medicine at no cost through the WHO.

Ivermectin also proved to be effective against lymphoid filariasis. In combination with other agents, it was found to be capable of treating and preventing this disease. River blindness and lymphatic filariasis are expected to be eradicated by 2025 and 2020, respectively.

■Figure 1 Number of people treated with ivermectin



Source: Professor S. Omura, Kitasato University

Dr. Omura was raised by his grandmother, rather than by his mother, who was busy working as an elementary school teacher. His grandmother repeatedly admonished him: "Above all, think about the good of the people." Even after becoming a researcher, he never forgot her words. Dr. Omura's research has indeed been an epoch-making achievement for the world, having saved hundreds of millions of people.

② Dr. Kajita's research achievement

After graduating from the Department of Physics, Faculty of Science, Saitama University in 1981, Dr. Kajita aspired to elementary particle research and entered Dr. Koshiba's lab at the graduate school of the University of Tokyo. Dr. Kajita was immediately invited by Dr. Arisaka, who had experimentally studied proton decay[1] at the Koshiba Laboratory, to do prep work for experiments with the Kamiokande device.

Charged particles are generated when a proton decays. When they pass through water, they emit a very weak light called Cherenkov light. In the experiments at the Kamiokande device, observations of Cherenkov light are made by using photomultiplier tubes attached to the inner surface of a tank filled with 3,000 tons of water. The team had to overcome successive challenges, such as how to secure the photomultiplier tubes in the water. With the help of Dr. Yoji Totsuka, who was an Assistant Professor in the Faculty of Science at the University of Tokyo, the Kamiokande device was finally completed in 1983.

Inside the Super-Kamiokande tank
Source: Kamioka Observatory, Institute for Cosmic Ray Research, the University of Tokyo

The Kamiokande device was originally intended to be used for the observation of very faint light generated by proton decay (Cherenkov light). However, after observation data was accumulated, the team found that by making a small improvement in a measuring instrument, they were able to observe solar neutrinos[2] reacting with water. This reaction produces weaker light than the Cherenkov light generated by proton decay. A proposal from Dr. Koshiba based on this fact prompted them to improve the Kamiokande device. In 1987, a supernova[3] occurred in the Large Magellanic Cloud, and neutrinos rained down on the earth in great numbers. The Kamiokande device took this opportunity to detect 11 neutrino reactions. Thanks to this achievement, Dr. Koshiba was awarded the Nobel Prize in Physics in 2002.

The Super-Kamiokande observation group
Source: Kamioka Observatory, Institute for Cosmic Ray Research, the University of Tokyo

In 1986, Dr. Kajita noticed that the observation data from the Kamiokande device did not match the theoretically predicted values. He suspected that neutrino oscillation[4] had occurred. This is a phenomenon whereby neutrinos on one type transform into those of a different type during they propagate over a long distance. When cosmic rays reach the Earth, they produce muon neutrinos and electron neutrinos by colliding with atomic nuclei in the air. Dr. Kajita hypothesized that muon neutrinos transform into another type of neutrino during their propagation. If neutrino oscillations were occurring, it would mean that neutrinos have mass. This would overturn the idea of a massless neutrino, an established part of particle physics at that time. In 1988, Dr. Kajita and his colleagues published a paper laying out this theory; however, it was not accepted by researchers at the time.

1 Proton decay is a phenomenon in which a proton, which is part of the atomic nucleus, becomes a positron, a photon, or another particle with a positive charge. Proton decay had been theoretically predicted. However, it has never been observed.
2 A solar neutrino is an elementary particle that cannot be subdivided. There are three types of neutrinos: electron neutrinos, muon neutrinos, and tau neutrinos.
3 A supernova is a large explosion that occurs when a star at least 8 times as massive as our sun reaches the end of its life. A supernova emits light that is brighter than a normal star, and neutrinos and gamma rays are also emitted in large amounts. Since the Large Magellanic Cloud is about 160,000 light-years from Earth, the detected neutrinos were emitted from a supernova that occurred about 160,000 years ago.
4 Neutrinos simultaneously have properties of particles and waves. Neutrinos fall into three kinds, according to their mass, and each type propagates as a wave with a different frequency.
Waves of electron neutrinos, muon neutrinos and tau neutrinos with different masses overlap. The wave phase of a neutrino changes during propagation, and the neutrino can become an electron neutrino, a muon neutrino or a tau neutrino.

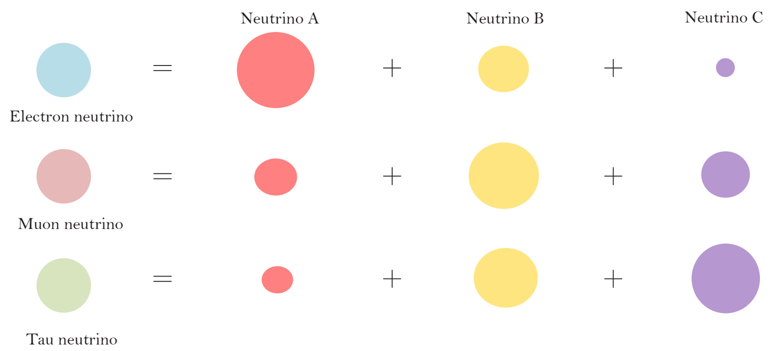
■Figure 2 Neutrino mixing and neutrino oscillations

Neutrino mixing

There are three “flavors”* of neutrino: electron, muon, and tauon.

There are also neutrino classifications by mass. Assuming that mass-classified neutrinos are named “neutrino A,” “neutrino B,” and “neutrino C,” the three flavors of neutrino are mixtures of neutrinos A, B and C.

This called neutrino mixing.



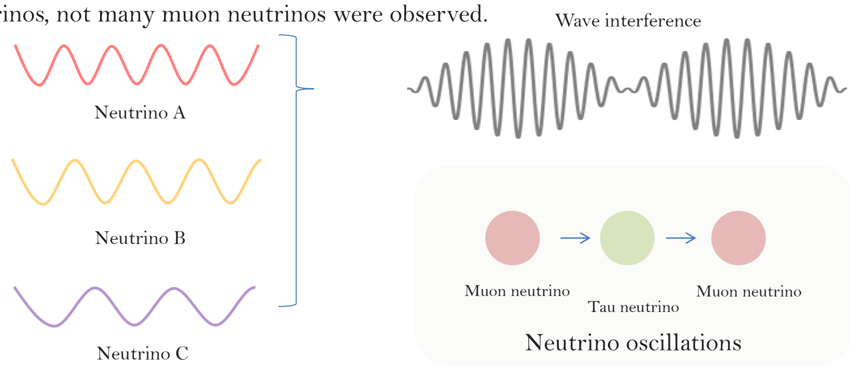
*A term that indicates the type of neutrino

Neutrino oscillations

Neutrinos are not only “particles” but also “waves” that oscillate. Neutrinos A, B and C each has a frequency of its own and propagates through space as “waves”.

The flavor of a neutrino results from interference among waves whose neutrinos_differ in mass. Therefore, while propagating the space, the flavor of a neutrino may change with changes in the wave phase.
This is called neutrino oscillation.

In the Super-Kamiokande experiment, because muon neutrinos changed to tau neutrinos, not many muon neutrinos were observed.

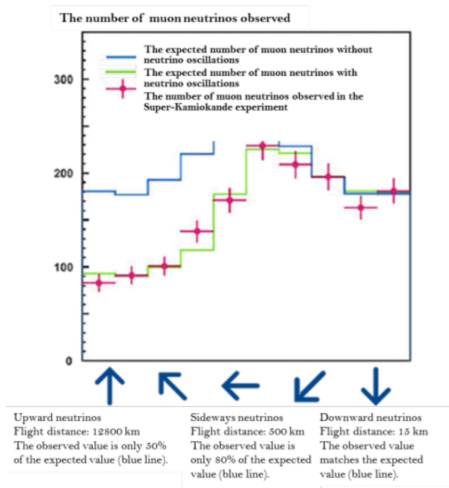


Source: MEXT

Neutrinos were observed only infrequently at the Kamiokande device, just once every few days. To test Dr. Kajita’s hypothesis experimentally, it was necessary to observe more neutrinos. To achieve this, it was necessary to enlarge the Kamiokande. The motto of Dr. Totsuka, who took over after Dr. Koshiba, was “In experimental physicists, data is life.” He supported Kajita’s hypothesis and led the construction of the

Super-Kamiokande, a device about 10 times the size of the Kamiokande device.

At the Super-Kamiokande, completed in 1996, a research team consisting of more than 100 members led by Dr. Totsuka and Dr. Kajita conducted observations around the clock. The team accumulated data until 1998. In the end, neutrino oscillations were observed. The data showed that the number of muon neutrinos coming from the dark side of the Earth was unexpectedly half of the predicted number. Normally, a roughly equal number of atmospheric neutrinos should come from every direction. Given that the propagation distance of atmospheric neutrinos coming from the back side of the Earth is long, this was an indication that neutrino oscillations had occurred. In 1998, Dr. Kajita announced conclusive evidence of neutrino oscillations at an international conference on neutrinos. At the venue, the applause that greeted this announcement attested to the greatness of the discovery.



Observation results of atmospheric neutrinos at the Super-Kamiokande
Source: Kamioka Observatory, Institute for Cosmic Ray Research, the University of Tokyo

Elementary particles, including neutrinos, came into existence 13.8 billion years ago, when the universe was born. If the nature of the neutrino can be clarified, it would be an important key to solving the mysteries of the universe. When the universe was born, matter and antimatter, whose charges are opposite, were created in identical amounts. Most of the antimatter disappeared, leaving mostly matter. There is said to be a slight difference in oscillation between neutrinos and anti-neutrinos. Elucidating the difference in the vibration is likely to be a breakthrough in explaining why most of the antimatter disappeared. To address the mysteries of the universe, it is believed that research equipment must be made more sophisticated.

(2) The key to winning the 2015 Nobel Prize

① The key to Dr. Omura's success

Among the factors behind Dr. Omura's research success, the distinguishing ones are teamwork-based research and the Omura method.

First, let us address teamwork-based research. Dr. Omura's research required teamwork, with different tasks assigned to each laboratory member, for example, separating the microorganisms that produce antibiotics, determining the structure of antibiotics and the like. To facilitate teamwork, Dr. Omura focused on fostering a certain laboratory ethos in which the leader advances the research under a collaborative system. Specifically, he constantly oversaw the work done by the laboratory staff, and he remembered to tailor his advice to the situation. The meticulous, ongoing attention paid by the lab leader to the lab personnel fostered an atmosphere in which everyone acted in concert on the steady, laborious work of finding microorganisms in soil that produce useful substances.

In addition, Dr. Omura assigned research themes to lab personnel who hadn't been thinking about pursuing doctoral degrees. How to tackle the research themes was left to the discretion of the lab personnel, and Dr. Omura encouraged them to take on challenges without fear of failure. As a result, they were made to work on research with a goal, and some of them earned doctorates. By carrying out research in which each laboratory member had a purpose, the entire laboratory was energized. Dr. Omura aimed at this outcome[1].

The research was done in collaboration with MSD. Dr. Woodruff of MSD, who liaised between Dr. Omura and MSD, understood the management methods of Dr. Omura's laboratory. Thanks to that understanding, the Kitasato Institute and MSD were able to build a role-sharing system that took advantage of the strengths of both[2]. This was one of the keys to success.

Another factor that led to the success of his research was the Omura method. This method involves joint R&D between a university and a foreign private company. It was a rare, epoch-making effort for its time. Dr. Omura's motto was, "Do things for people." For his work to be valuable to people, he needed to do more than just discover, isolate and determine the structure of chemical substances derived from microorganisms. The research had to become useful to the world through drug discovery. Dr. Omura's industry-university joint research with a pharmaceutical company was essential in helping the research results reach the people of the world.

The Omura method follows the process below. First, an institute obtains research funds from a company. The institute uses the funds for research and acquires patents. The institute assigns exclusive patent rights to the company. The company bears the costs of applying for patents and maintaining the patent rights. The research results obtained by the institute are provided to the company. The company commercializes the results and pays a running royalty to the institute in accordance with the sales of the company's product. In this way, an intellectual creation cycle is established whereby the institute (and the inventors) is funded and subsequent research results follow.

Dr. Omura signed a contract with MSD as follows[3].

(i) The Kitasato Institute and MSD shall develop a collaborative relationship in the R&D on antibiotics for animals, enzyme inhibitors for animals, and broad-spectrum antibiotics.

(ii) MSD shall pay 80,000 dollars a year over the next 3 years for screening and research on chemicals conducted by the Kitasato Institute.

(iii) MSD shall exclusively hold the patents that derive from the research results, and MSD shall also hold the secondary patent rights.

(iv) However, if MSD no longer needs the patent rights but the Kitasato Institute does need those rights, then MSD shall relinquish the rights.

(v) If any products they rely on patents are sold, MSD shall pay royalties to the Kitasato Institute at patent royalty rates for net sales that are congruent with those around the world.

MSD sold ivermectin as an animal drug that was an improved version of avermectin, which had been discovered by Dr. Omura. The product was a hit, and it became one of the best-selling animal drugs in the world. Furthermore, the Kitasato Institute earned up to 1.5 billion yen in patent royalties a year. With the royalty income, Dr. Omura developed a research environment that would allow him to catch up with the United Kingdom, which had a roughly 3-year lead in the genetic analysis of actinomycetes bacteria. In addition, he achieved the feat of decrypting 99.5% of the genome of the actinomycetes species [4] that

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1 A Chemist Defends 200 Million People from a Disease - Satoshi Omura (2012) written by Rensei Baba, published by ChuoKoron Shinsha

2 Dr. Omura's group had sufficient technique to analyze bacteria and determine bacterial structure. MSD had a wealth of experience in safety testing and R&D, and it was an excellent strategist on patents.

3 The details of the contract between the Kitasato Institute and MSD are excerpted from A Chemist Defends 200 Million People from a Disease - Satoshi Omura (2012) written by Rensei Baba, published by ChuoKoron Shinsha

4 Streptomyces avermitilis

produces the active ingredient in avermectin. In addition, with these royalties, he built a 440-bed hospital in Kitamoto City, Saitama Prefecture, for a research center with the aim of contributing to society.

② The key to Dr. Kajita's success

(i) Government support for large-scale projects

Dr. Kajita's research results owe to the Super-Kamiokande, a large-scale detection facility. The Super-Kamiokande, which is used for neutrino research, was built from FY1991 to FY1995 with an investment of about 10.4 billion yen as a large-scale project that should be promoted by Japan.

In recent years, large-scale projects such as Dr. Kajita's research have been promoted around the world. Thanks to this trend, epoch-making results have been achieved. For example, theories born from theoretical studies several decades ago have been experimentally confirmed. A specific example is the Nobel Prize in Physics for 2013, which was given to the two people who had predicted the existence of the Higgs boson. From experiments at the Large Hadron Collider (LHC) of the European Organization for Nuclear Research (CERN), the presence of the Higgs boson was confirmed about 50 years after its prediction. In addition, the gravity waves predicted by Albert Einstein 100 years ago were experimentally verified. The findings were announced by the Laser Interferometer Gravitational-Wave Observatory (LIGO) in the U.S.A. in February 2016. This is still fresh in our minds.

In contrast, the research results that Dr. Kajita obtained from the Super-Kamiokande data was a remarkable achievement, in that the results overturned the established theory of the massless neutrino, which had been predicted under the standard model of physics based on theoretical work. Those experimental results prompted a reevaluation of theory.

As seen above, large-scale projects in physics achieve results through the efforts of two sides of the same coin: theoretical research and experimental verification. However, projects of that scale require great investments over a long period of time; therefore, it has become a challenge to smoothly promote projects under the severe financial constraints of recent years.

For this reason, it is necessary to get a wide range of support from society and the public, as well as from the research community. The Institute for Cosmic Ray Research of the University of Tokyo, which owns the Super-Kamiokande, has taken measures to explain its research results to the public in a plain way and to obtain the public's understanding of its research results, such as by holding events in cooperation with the local government, which enables tours of the experimental facility, and by holding exhibitions for the public at locations outside the facility. These locations include SkyDome Kamioka, a roadside rest area, and the National Museum of Emerging Science and Innovation. Other provision of easy-to-understand information regarding the research results includes tours and lectures for junior high and high school students from schools designated Super Science High Schools (SSH) and the brochure *Understanding in 5 minutes! The Secrets of the Neutrino*, for easy comprehension by children. The High Energy Accelerator Research Organization (KEK) frequently conducts outreach activities, such as holding open houses and publishing the cartoon series "Kasoku Kids (Accelerator Kids)."

(ii) The promotion of research under a system of shared use and joint research

Neutrino research at the Super-Kamiokande facility, where Dr. Kajita's results were achieved, has been carried out under a system of shared use and joint research. This system is unique to Japan. Its features are as follows. a) Researchers in related fields jointly develop (and improve and enhance) large-scale research equipment and share it. b) Large amounts of research materials and data are collected and stored, which is difficult for an individual university to do. These are shared with researchers in related fields. c) Joint research and research meetings are organized such as to contribute to the development of the relevant research fields and facilitate exchanges of researchers. Although there are variations depending on the nature of the research field, generally the system has brought together the knowledge of researchers, and it has promoted joint research in line with the wishes of the research community. The system has been used for neutrino research at the Super-Kamiokande: Graduate students and young researchers from a number of research institutions have pooled their knowledge and have participated in the development and improvement of research equipment and the collection and maintenance of data. These efforts contributed greatly to the research results of Dr. Kajita.

A photomultiplier tube
Source: Kamioka Observatory, Institute for Cosmic Ray Research, the University of Tokyo

(iii) The technical capabilities of Japan's private sector

The success of Dr. Kajita's research owes largely to two companies: the Organo Corporation, which had rich experience in the electronics industry and manufactured an ultrapure water production system, and Hamamatsu Photonics K.K. (hereinafter: Hamamatsu Photonics), which manufactured highly sensitive photomultiplier tubes.

The photomultiplier tubes that were manufactured by Hamamatsu Photonics, and were installed in the Super Kamiokande are extremely large, with a diameter exceeding 50 cm. Hamamatsu Photonics is the only company in the world that is capable of developing such equipment. Demands had been made of Hamamatsu Photonics to achieve high performance. These demands had come from Dr. Koshiba during the construction of Kamiokande, and from Dr. Kajita during the construction of the Super Kamiokande. To address these demands, Hamamatsu Photonics made full use of their technical capabilities, sometimes thoroughly discussing matters with the researchers of the institute[1].

In addition, superconducting wire manufactured by Furukawa Electric Co., Ltd. is used as a superconducting material for the electromagnet coils in the LHC accelerator, which contributed to the elucidation of the Higgs boson. And the above-mentioned Hamamatsu Photonics developed a silicon detector. As seen above, Japanese companies have contributed to the development of large-scale, cutting-edge research facilities. Domestic Japanese companies that have outstanding technological capabilities are valuable to Japanese research institutions that carry out the world's most advanced research.

Such large-scale research facilities require regular maintenance, various upgrades, accuracy improvements and the like. Domestic Japanese companies that stand out in being able to do such work are

1 "Sources of R&D Capabilities in Hamamatsu Photonics K.K." (2013) written by Naohiro Shichijo, Junichi Murata, Shinichi Akaike, and Atsushi Ogasawara, included in Hitotsubashi Business Review, published by Toyo Keizai Inc.

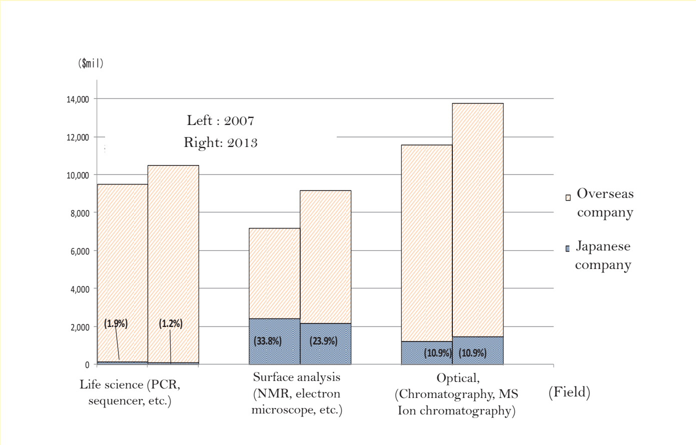
critical for smooth research activities. The Super-Kamiokande had a major accident in 2001 in which about half of the photomultiplier tubes were damaged. However, the facility was able to recover in one year, owing to Hamamatsu Photonics's presence in Japan and the ability of the company to closely collaborate with the Super-Kamiokande experiment group.

Column Feature 1 — Measurement and analysis equipment for supporting science and technology

The Nobel Prizes of Dr. Kajita and Dr. Omura could not have been won without advanced measurement and analysis equipment, such as high-performance photomultiplier tubes with which to measure the patterns of Cherenkov light and thus to allow the identification of electrons and muons[1], and nuclear magnetic resonance (NMR[2]) devices, which were once installed in Japan in very limited numbers.

In the 21st century, Nobel Prizes in the natural sciences, if limited to awards for measurement and analysis technology itself, number six, including the award given to Dr. Koichi Tanaka (Senior Fellow at Shimadzu Corporation). It is certainly not too much to say that measurement and analysis is the "mother of science," playing an important role in scientific and technological capabilities.

Next, let' s shift our focus to industry. The world share of Japanese-made equipment for measurement and analysis varies by the type of equipment. The international competitiveness of some types of measurement and analysis equipment, which supports industry, is low. The right-hand figure shows the market for each type of measurement analysis equipment and the share of those markets held by domestic Japanese companies in 2007 and 2013. The competitiveness of Japan in measurement and analysis equipment varies by equipment type. Overall, Japanese industry excels in materials analysis but not in the life sciences. As shown in the figure, Japanese industry has less than a 2% share of measurement and analysis equipment related to the life sciences. The Japanese global market share of surface analysis equipment is about 30%.This greatly owes to optical microscopes (33% in 2013) and electron microscopes (29% in the same year). NMR equipment was utilized in Dr. Omura's research; however, Japan's global market share for such equipment is only 7.0% (2013).



Global market share of Japanese measurement analysis equipment, by type

Source: MEXT (based on SDi Global Assessment Report, 2014 and 2009 editions)

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1 These are elementary particles that can penetrate bedrock to a thickness of 1 km. The particles are generated in the upper atmosphere, and they continuously rain down on the ground at about 1 per cm^2 per minute.

2 This is high-performance observation equipment that detects the differential absorption of specific electromagnetic waves by nuclei under a strong magnetic field (nuclear magnetic resonance, NMR), and separates the atoms that make up the molecule. When Dr. Omura was enrolled in the graduate school of the Tokyo University of Science, very few NMR units were installed in Japan, and none at any university in Japan. He continued his research to determine the structure of organic compounds by using a NMR device that was only operated at Tokyo Industrial Research Institute.

Strengthening the Competitiveness of Japan's Analytical Equipment Industry (2011), a report made by the National Institute of Advanced Industrial Science and Technology, analyzed the state of the measurement and analysis equipment industry in Japan. It reported that it takes 10 to 20 years for new analysis equipment to become popular and accepted by researchers and engineers. However, it is difficult for Japanese companies to overcome what has been called "the valley of death," which is the 3-year window for a company to turn a profit on a new product.

In addition, *Research and Development Trends in Measurement Technology* (2013) and *the Workshop Report of the Nano-Measurement Technology Subcommittee* (2014), which are investigation reports published by the Japan Science and Technology Agency, pointed out the following: Many types of measuring equipment manufactured by foreign companies have become internationally standard. However because many of the core technologies in Japan are excellent, from now on, industry-academia-government collaboration is necessarily for systematizing such core technologies towards making them internationally standard. It is also necessary to create an environment in which different stakeholders can communicate and collaborate from the early stage of development.

Also, the 5th Science and Technology Basic Plan positions measurement analysis technologies as common base technologies that support research and development. In maintaining and sophisticating common core technologies, one key is the establishment of a long-term support system by the Japanese government that will enable superior technologies of Japan to be commercialized and measurement and analysis equipment to be continuously developed.

Column Feature 2

Interview with Dr. Omura

○ What motivated you to want to be a scientist or a researcher?

◇ At school, I preferred science to English and Japanese, but a more significant influence on me was the teaching of my grandmother, who told me, "Do what helps people." In high school, I started thinking 'Hey, I actually like science," and I decided to enroll in the Faculty of Liberal Arts and Natural Science at the University of Yamanashi. In those days, the University of Yamanashi had what it called a meister system, which allowed an open research environment for students regardless of their year. Even first-year students could conduct the experiments they wanted to do with assistants or students in their final year who were working on their graduation research. That was quite good.

Satoshi Omura, Distinguished Emeritus Professor of Kitasato University
Source: the Kitasato Institute

○ It's been pointed out that kids have been turning away from scientific subjects.

◇ Once students have enrolled in university, there's no point in telling them to take an interest in elementary particles. What's necessary is education that will interest elementary school students in science. It's true that the Super Science High School program is a good program, but I think similar projects are needed for elementary and junior high school students. To realize this, good science teachers are needed. I might suggest that salaries for science teachers be raised by 10% to secure excellent human resources. I established a public interest incorporated association called the Yamanashi Academy of Sciences. We've been holding seminars called 'Visits to future scientists' for 20 years. Researchers with connections to Yamanashi Prefecture visit elementary, junior high and high schools in Yamanashi Prefecture to give seminars. Demand for the visits is high, and as many as 30 visits are made in a year. As a child, I'd go eeling at night at the river with my father. He told me the eels came upstream from the Pacific, which made me wonder what eels would be doing in Yamanashi, where there weren't any seas. Experiences like these are the beginning of science, and I think it's important for children today to have similar experiences.

The Yamanashi Academy of Sciences
Source: Satoshi Omura, Honorary Professor Emeritus at Kitasato University

○ How has what you learned at the University of Yamanashi influenced your life as a researcher?

◇ The University of Yamanashi was formerly a teachers' college. It became the local national university after the war. Partly because of the policies of the first president, the University of Yamanashi was unique and aimed to contribute to the development of local businesses that took advantage of the features of the area. One example that showed the uniqueness of the university was the establishment of the Department of Fermentation Production. The University of Yamanashi also engaged in research on synthetic quartz, because quartz is a local product of Yamanashi Prefecture. Unlike teachers who just copy the textbook onto the blackboard, the teachers there enjoyed challenges; some were trying to make quality wine and others were trying to fabricate larger quartz crystals. Likewise, research sites shouldn't be centralized. It is important for the government to create an environment in which a variety of research can emerge from areas around Japan.

○ A decline in the number of applicants for doctoral courses has also been pointed out. Do you have any thoughts on fostering young researchers?

◇ What's important is let them work on research they're really interested in and they want to do. They should be taught research basics when they join a lab, of course. But if they're doing the same things as their Ph.D. advisor does or assisting the advisor, they'll never surpass their advisor. At some point, they have to be allowed to freely research what they want. At the very least, when a young researcher becomes an associate professor, it's inadvisable for the associate professor to work under the instruction of a professor. Ph.D. advisors need to protect their protégés for some time by providing a good research environment, such as by securing research funds or introducing places to study abroad. Advisors should be careful about timing the transition from protecting their protégés to encouraging them to become independent researchers.

○ The inward-looking nature of young researchers has been mentioned. What do you think is behind this?

◇ I think young researchers' inward-looking nature may lie in elementary and lower secondary education. As small children, they should receive education that encourages them to enjoy challenges and to have ambition. Without that, it's very tough for them to show such attitudes once they've enrolled in a university. I can also say, from personal experience, that exchanges with researchers overseas are extremely important. In my case, I've treasured relationships with researchers overseas whom I met at scientific meetings and may never meet again by continuing to exchange letters and cards. In that way I was able to establish a broad network of researchers overseas, and I can use it to find places overseas for students in my lab to go and study. Needless to say, skill in writing papers in English is indispensable, so I have special staff for review and training.

○ It has been pointed out that the growing number of fixed-term posts has adversely affected young researchers, making their status insecure and preventing them from concentrating on their research.

◇ I haven't given much thought to that, since all the young researchers in my lab are fortunate to have found good positions. It may be that the system for postdoctoral researchers hasn't been functioning properly. I've accepted postdoctoral researchers in my lab since before the government established a system for them. I think the problem lies with both businesses and universities. Businesses are no more eager to hire doctoral graduates than they have ever been. Students mistakenly believe they're big researchers once they've received a doctorate, and they have little determination to contribute to the development of a company.

○ The need for actual industry-academia collaboration to be promoted has been pointed out. As a leader of industry-academia collaboration, how do you see the current situation?

◇ At first, the idea of joint research with Merck Sharp & Dohme Corp (MSD) wasn't in my mind. Professor Tishler was very helpful when I was studying at Wesleyan University, but I didn't decide to do joint research with MSD just because he was a former director of the MSD lab. The fact is that the Kitasato Institute had asked me to look for ways of doing joint research with the NIH or other institutions. While I was visiting those institutions to ask for their cooperation with the Kitasato Institute, I began to think it might be better for the Kitasato Institute to conduct research jointly with a business if we were going to do research that incorporated practical learning. And Professor Tishler kindly spoke to MSD about seeing me, so the decision ended up being for joint research with MSD. I can say from personal experience that universities must sell themselves to companies by showing something concrete, in other words "sales points," that might be needed by a company. Vaguely proposing industry-academia collaboration or doing something together gets you nowhere. Our case went well because I was able to clearly show how strong the Kitasato Institute was in research on microorganisms, what kind of human resources we had, and what we were capable of.

○ You often mention the phrase 'manage research.' What do you mean by that?

◇ If you receive research funds from a business, you have to do research that meets the expectations or demands of the company. That was what I thought from the outset. In industry-academia collaborations, the company and the university bring together what each one has, and if something is lacking, they need to discuss what that is and fill the gap. In that sense, a researcher, too, is a 'manager' and needs to have managerial sense. 'Managing' also means 'fostering human resources.' Have a clear list of research topics for the industry-academia collaboration. Present ideas. Use funds obtained through joint research to foster human resources by preparing posts for young researchers or sending them overseas. Return the fruits to society. If such a cycle can be established properly, money will come in from society and human resources will grow.

Column Feature 3

Interview with Dr. Kajita

○ What motivated you to want to be a scientist or a researcher?

◇ I can't say exactly, but I remember that when I was in high school I took an interest in physics because "it was a subject where you could understand things in a simple way." Also, the high school teacher who was in charge of the Japanese archery club to which I belonged was a science teacher who'd completed a graduate course and majored in physics. That may have had a big influence on me. And in my case, I received poor marks in Japanese language, so by process of elimination, I decided to pursue the natural sciences.

Takaaki Kajita, Director of the Institute for Cosmic Ray Research, the University of Tokyo
Source: MEXT

○ It's been pointed out that kids have been turning away from scientific subjects.

◇ I'm not too familiar with the situation, as the Super Science High School program has me meeting children of high school age or younger face to face only twice a year, at Kawagoe High School in Saitama Prefecture. For projects like the Super Science High School program, I think the gates should be open wider, rather than focusing on smaller targets. For example, when we look at where teachers at the Institute for Cosmic Ray Research are from, we see they come from various places. In Asian countries, elites are selected early on. If you're not chosen, it's all over by then. But in Japan, students can try again at various stages. I think that's an advantage of Japan.

In a similar sense, one of the few advantages left to Japan is that there are widening paths for students. National universities are located around the country, and students who receive undergraduate education at some local universities can enroll in the graduate school of the University of Tokyo, for example.

○ After graduating from Saitama University, what made you proceed to the study of elementary particles at the University of Tokyo?

◇ When I was ready to take the entrance exams for graduate school, I decided to pursue the study of elementary particles and cosmic rays at graduate school. I made the decision on my own. And I didn't think I was suited to theoretical studies, so I chose to pursue experimental studies.

○ A decline in the number of applicants for doctoral courses has also been pointed out. Do you have any thoughts on fostering young researchers?

◇ In my case, I didn't think much about future posts and I didn't worry about finances, because I genuinely wanted to study physics at graduate school. Providing proper support to young researchers, including to post-grads, is the key to enhancing Japan's prowess in science and technology. At present, support for post-graduate students is completely insufficient. Various support programs do exist, but they have time limits. It seems to me that some are lucky enough to benefit from those program and others are not, depending on the timing.

○ The inward-looking nature of young researchers has been mentioned. What do you think is behind this?

◇ At the Institute for Cosmic Ray Research, few people in the doctoral course go abroad to study. But quite a lot do so after their postdoctoral period, and people whose field of research has a base overseas go abroad relatively free from anxiety, so I haven't been very aware of this trend. In general, I think it might be good for young researchers to go abroad during their doctoral course or while they're a postdoctoral fellow or an assistant professor. In recent years, however, universities are less able to let young researchers go abroad to study after they get a position as an assistant professor or the like, making it difficult for young researchers to go abroad to study. Besides, there used to be fewer positions for postdoctoral researchers in Japan, so they'd go abroad first and wait there until a position was available for them in Japan. In contrast, there are various posts for postdoctoral fellows now, but it's hard for them to find a post after that.

But even today, I think young researchers should go abroad. Building international networks is extremely important in the world of international science. I think Japan is lagging in this respect. Furthermore, doing research in a different place with a different culture will allow them to take in various things and broaden their capabilities, even if the research they'll be working on is the same as what they were doing in Japan.

○ It has been pointed out that the growing number of fixed-term posts has adversely affected young researchers, making their status insecure and preventing them from concentrating on their research.

◇ This problem really needs to be tackled. Since 2000, enrollment in doctoral courses has been on the decline, even at the University of Tokyo. Students are well aware that finding regular jobs is increasingly difficult for young researchers. This is a really serious problem for Japan's scientific and technological future. To do research that might win them a Nobel Prize, they need to have a stable position. If they're in a research environment where they're holding a fixed-term position and have to churn out papers during that fixed period, it's going to be hard for them to engage in research that will lead to a Nobel Prize. In my case, after the first 2 years of being in a fixed-term position, I took a position without fixed term, and this enabled me to settle down and study. Taking superficial measures to improve the situation won't work. What's most important is to secure stable positions for young researchers.

In addition, young researchers are not only ones who have been very busy with various duties. Therefore, they have fewer hours for their research than they used to have. Nothing can remedy this situation.

○ Were your studies influenced much by the availability of large-scale facilities for observation and experiment in Japan, such as the Super-Kamiokande detector?

◇ Regarding the Super-Kamiokande, it was of great significance that Japan, as the host country, took the initiative in using it to promote observation and research and that the facility was internationally recognized. On the other hand, at least in some fields, the scale of facilities required for study is getting larger and larger--too large to be maintained by a single country. So the global trend is to develop facilities through international collaboration. What facilities need to be maintained in a country by that country alone depends on the field, I think.

○ What do you think about the career paths for postdoctoral fellows becoming double-track ones?

◇ It's necessary for society to properly explain to young people that there are various career paths. There seems to be many cases in which postdoctoral fellows who aim to be researchers work hard past their mid 30's only to give up after they're 40. I think we need to transform our society into one that doesn't abandon such people. Traditionally in Japan, young people are hired, but it's hard for people over 40 to be hired. It's crucial for us as a society to change this situation, even if that change is difficult to realize.

2 Looking Back on Previous Japanese Nobelists

(1) What is the Nobel Prize?

The Nobel Prize was established based on the wishes of Alfred Nobel, the inventor of dynamite. At first, the prize categories consisted of physics, chemistry, physiology or medicine, literature, and peace. The Prize in Economic Sciences was added in 1969, but this was not based on the wishes of Alfred Nobel.

Nobel Prizes have been awarded 573 times to 900 individuals and organizations between 1901 and 2015.[1] 48 laureates have been women. The average age for a Nobel laureate is 59. The youngest laureate was 17, and the oldest was 90.[2] Each category is intended for the following people and/or organizations.

- Nobel Prize in Physics: awarded "to the person who shall have made the most important discovery or invention"
- Nobel Prize in Chemistry: awarded "to the person who shall have made the most important chemical discovery or improvement"
- Nobel Prize in Physiology or Medicine: awarded "to the person who shall have made the most important discovery"
- Nobel Prize in Literature: awarded "to the person who shall have produced in the field of literature the most outstanding work in an ideal direction"
- Nobel Peace Prize: awarded "to the person who shall have done the most or the best work for fraternity between nations, for the abolition or reduction of standing armies and for the holding and promotion of peace congresses"

Winners in physics, chemistry, and economic sciences are decided by the Royal Swedish Academy of Sciences. Winners in physiology or medicine are decided by the Nobel Assembly of the Karolinska Institutet. Winners in literature are decided by the Swedish Academy. Peace prizes are decided by the Norwegian Nobel Committee. For the three natural sciences, the Nobel Prize awarding institutions solicit nominations for the coming year by sending letters to thousands of major research institutions and universities worldwide, collect those nominations and narrow them down, and announce the Nobel laureates in October. Only nominees are eligible for the prize. The Nobel Prize Award Ceremony is held on December 10, the anniversary of Alfred Nobel's death. Days before and after the ceremony are designated as Nobel Week, during which lectures, banquets and other events are held.

This section deals with Nobel laureates in the three prize categories of natural sciences, that is, physics, chemistry, and physiology or medicine.

1 The Nobel Peace Prize can be awarded to organizations.
2 The data are from the official website of the Nobel Prize.

Column
Feature 4

The Nobel Prize in economic sciences

In the late 1960's, Sveriges Riksbank, Sweden's central bank, suggested to the Royal Swedish Academy of Sciences that a Nobel Prize in economics be established, to recognize the importance of that science. The suggestion was accepted. The award is officially called "the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel." 75 people received the prize between 1969, when the prize was first awarded, and 2015. Most of the laureates have been from developed nations in the Western world, including 52 from the U.S.A. and 8 from the UK. The first and only Nobel Prize in Economic Sciences to be awarded to an Asian was to Dr. Amartya Sen[1], from India, in 1998. A look at the fields of study finds that 9 of the laureates specialized in macroeconomics and 8 in econometrics. Since 1990, the award has been given to 8 laureates specializing in monetary economics, 8 in game theory and 5 in the economics of information[2].

The integration of economic sciences with other fields of study has accelerated recently. Standard economic theories presume "homo economicus (economic man)," an idealized human who is assumed to act rationally all the time and to take measures to pursue his or her own best interests. In reality, however, people have feelings and exhibit complicated behaviors, and this needs to be taken into consideration[3]. Daniel Kahneman of Princeton University, who received the Nobel Prize in Economic Sciences in 2002, demonstrated that "human decision-making can systematically diverge from the predictions of standard economic theories." In standard economics, gains and losses are considered to be equal. However, integrated research in economic science and psychology shows, for example, that humans feel a loss more keenly than they feel an equal gain.

Not only have Nobel laureates contributed greatly to academia, but they've also contributed to economic policies of governments and international institutions. For example, Dr. Joseph E. Stiglitz, who received the Nobel Prize in Economic Sciences in 2001, served as the chair of the Council of Economic Advisers to the President of the U.S.A., and Dr. Paul Krugman, who received the Nobel Prize in Economic Sciences in 2008, was a member of the Council of Economic Advisers to the President of the U.S.A. and an economic consultant to the World Bank.

The 5th Basic Plan states the following: Towards creating innovations that originate in Japan, a mechanism will be established whereby all the actors will be able to utilize their abilities to the fullest with the participation of every field, from humanities to social sciences to natural sciences. This will lead to Japan being the most innovative country in the world. In light of this, continued support that is necessary to promote the humanities and the social sciences is important if Japan is to improve its research standards in those disciplines, including economic sciences, to participate in international networks of scientists and to contribute as a country on various occasions.

(2) Changes in the lineup of Nobel laureates

① Changes in the nationalities of Nobel laureates

Looking at historical changes in the nationalities of Nobel laureates in the three categories of natural sciences, the numbers of laureates from the U.S.A. and Europe were roughly equal from 1901 to 1990. From 1991 to 2000, the U.S.A. had superior numbers. In the current century, Japan has the second-most Nobel laureates in the natural sciences, after the U.S.A. (Table 1).

1 Professor Amartya Sen is now affiliated with Harvard University.
2 For the number of Nobel laureates by fields of award, see the official website of the Nobel Prize (www.nobelprize.org).
3 Tomono, Norio (2006) Behavioral Economics: The Economy is Driven by Emotion. Kobunsha

■ Table 1 Nobel laureates per country (natural sciences)

	1901-1990	1991-2000	2001-2015	Total
USA	156	39	55	250
UK	65	3	10	78
Germany	58	5	6	69
France	22	3	6	31
Japan	5	1	15	21

Note 1: MEXT created this tentative table based on announcements by the Nobel Foundation and other information sources.

Note 2: Of the Japanese laureates, Dr. Yoichiro Nambu, the 2008 laureate in physics, and Dr. Shuji Nakamura, the 2014 laureate in physics, had U.S. citizenship when they received their prizes.

Note 3: For laureates other than Japanese ones, the nationalities were counted in a following manner. The laureate's nationality was taken as that published by the Nobel foundation at the time he or she won the prize. For dual nationals, the country of birth was taken as the nationality. For laureates about whom neither of the above was known, the country that was the principle base of activities was counted.

Source: MEXT

② The number or years between the scientific discovery that led to the Nobel Prize and the year the prize was awarded

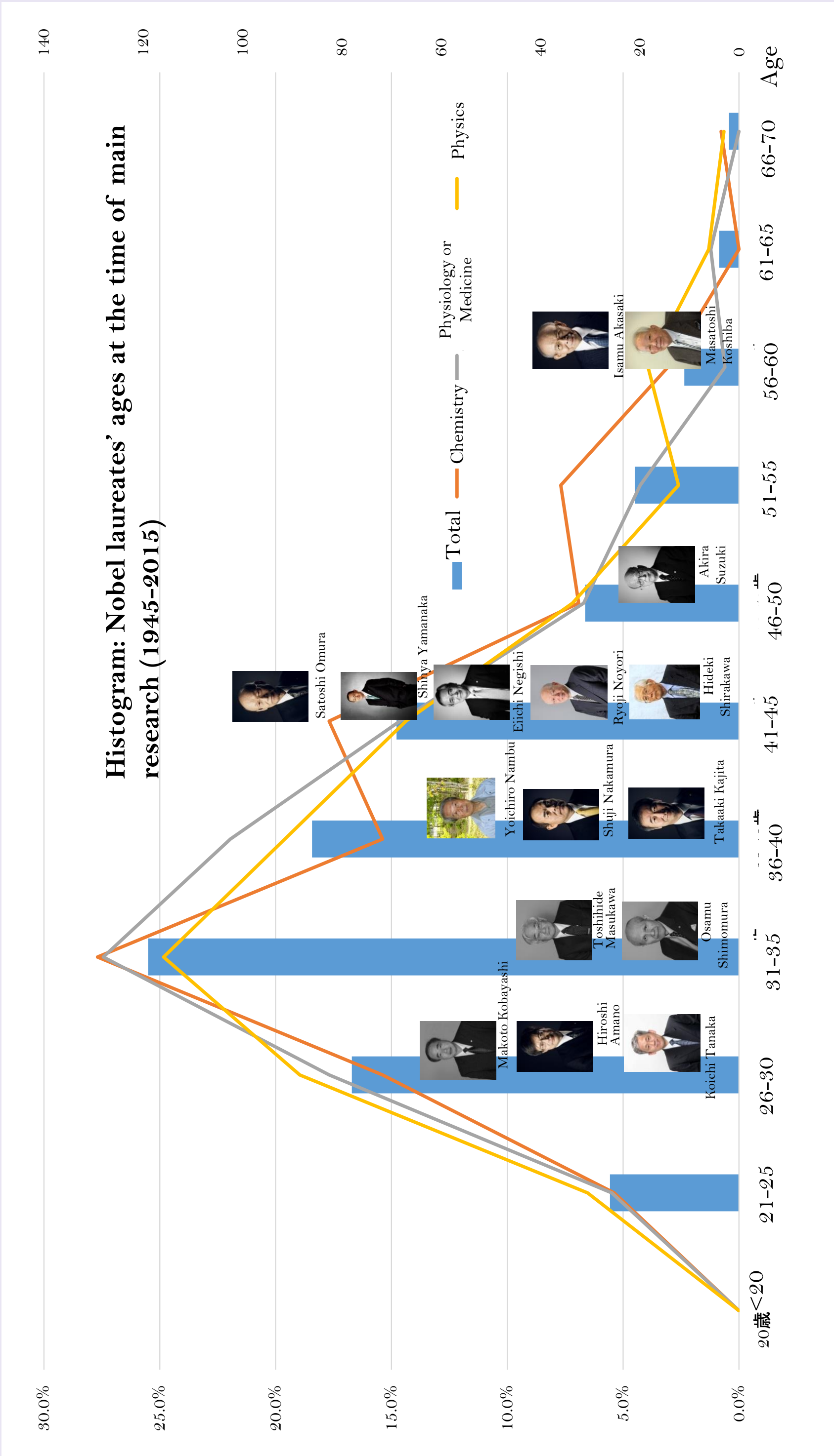
Laureates' ages at the time of their wins, research achievements that led to their wins (such as papers), and the period in which the research was conducted were disclosed when the Nobelist was awarded the prize. Based on that information, the age of Nobel laureates since the 1940's at home and abroad at which they produced research achievements which led to the Nobel Prizes were identified. It is shown that, on average, the research achievements that led to the win are mainly those produced when the laureate was in his late 20's or 30's, in all 3 categories (Figure 3).

■ Table 2 Japanese Nobel laureates (in natural sciences)

Year	Name (age at the time of the award)	Age at which the laureate conducted the research that led to the Nobel Prize	Category	Research Leading to the Prize
1949	Dr. Hideki Yukawa (42)	27	Physics	"for his prediction of the existence of mesons on the basis of theoretical work on nuclear forces"
1965	Dr. Shinichiro Tomonaga (59)	41	Physics	"for their fundamental work in quantum electrodynamics, with deep-ploughing consequences for the physics of elementary particles"
1973	Dr. Reona Esaki (48)	32	Physics	"for their experimental discoveries regarding tunneling phenomena in semiconductors and superconductors, respectively"
1981	Dr. Kenichi Fukui (63)	34	Chemistry	"for their theories, developed independently, concerning the course of chemical reactions"
1987	Dr. Susumu Tonegawa (48)	39	Physiology or Medicine	"for his discovery of the genetic principle for generation of antibody diversity"
2000	Dr. Hideki Shirakawa (64)	41	Chemistry	"for the discovery and development of conductive polymers"
2001	Dr. Ryoji Noyori (63)	42	Chemistry	"for their work on chirally catalysed hydrogenation reactions"
2002	Dr. Masatoshi Koshiba (76)	60	Physics	"for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos"
2002	Dr. Koichi Tanaka (43)	26	Chemistry	"for their development of soft desorption ionisation methods for mass spectrometric analyses of biological macromolecules"
2008	Dr. Yoichiro Nambu (87)	39	Physics	"for the discovery of the mechanism of spontaneous broken symmetry in subatomic physics"
2008	Dr. Makoto Kobayashi (64)	28	Physics	"for the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature"
2008	Dr. Toshihide Masukawa (68)	33	Physics	
2008	Dr. Osamu Shimomura (80)	34	Chemistry	"for the discovery and development of the green fluorescent protein, GFP"
2010	Dr. Eiichi Negishi (75)	41	Chemistry	"for palladium-catalyzed cross couplings in organic synthesis"
2010	Dr. Akira Suzuki (80)	49	Chemistry	
2012	Dr. Shinya Yamanaka (50)	43	Physiology or Medicine	"for the discovery that mature cells can be reprogrammed to become pluripotent"
2014	Dr. Isamu Akasaki (85)	57	Physics	"for the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources"
2014	Dr. Hiroshi Amano (54)	26	Physics	
2014	Dr. Shuji Nakamura (60)	39	Physics	
2015	Dr. Satoshi Ōmura (80)	44	Physiology or Medicine	"for their discoveries concerning a novel therapy against infections caused by roundworm parasites"
2015	Dr. Takaaki Kajita (56)	39	Physics	"for the discovery of neutrino oscillations, which shows that neutrinos have mass"

Source: MEXT

■ Figure 3 Age at which the laureate conducted the research that led to the Nobel Prize



Photos: Copyright © The Nobel Foundation (for the photos of Dr. Kobayashi, Dr. Masukawa, Dr. Shimomura, Dr. Negishi , Suzuki, Dr. Yamanaka taken by U. Montan)
Photos: Copyright © The Nobel Media Photo (for the photos of Akasaki, Amano, Dr. Nakamura, Dr. Kajita, Dr. Omura taken by A. Mahmoud)
Photo: Copyright © Kazuhiko Kanno (for the photo of Dr. Shirakawa)
Materials are collected by NISTEP and the SciREX Center of the National Graduate Institute for Policy Studies.

Source: NISTEP and the SciREX Center of the National Graduate Institute for Policy Studies.

Looking at the number of years between when the laureates conducted the research that led to the Nobel Prize and when they received the prize, the average is shown to be about 20 years, although it was increasing over the period from 1940's to 2010's. As for the average lag for Japanese laureates since 2000, their achievements that led to the Nobel Prize were produced about 30 years before their win (Table 3).

■ Table 3 Average age at which the laureate conducted the research that led to the Nobel Prize[1], the average number of years between the year in which the laureate conducted the research that led to the Nobel Prize and the year of the win, and the average age at which the laureate received the prize

Awarded	Age at which the laureate conducted the research that led to the Nobel Prize	Number of years between the year in which the laureate conducted the research that led to the Nobel Prize and the year of the win	The average age at which the laureate received the prize
1940'	35.3	18.5	53.8
1950'	36.3	15.1	51.4
1960'	35.5	18.3	53.8
1970'	36.7	20.1	56.8
1980'	37.0	21.9	58.9
1990'	36.4	24.5	60.9
2000'	40.0 (37.9)	26.2 (30.3)	66.1 (68.1)
2010'	36.6 (42.3)	29.2 (25.3)	65.8 (67.5)
Total	37.1 (40.1)	22.0 (27.8)	59.0 (67.8)

Note: Values in parentheses are values for the Japanese laureates since 2000.
Source: MEXT compiled the material based on data collected by the National Institute of Science and Technology Policy (NISTEP) and the SciREX Center of the National Graduate Institute for Policy Studies.

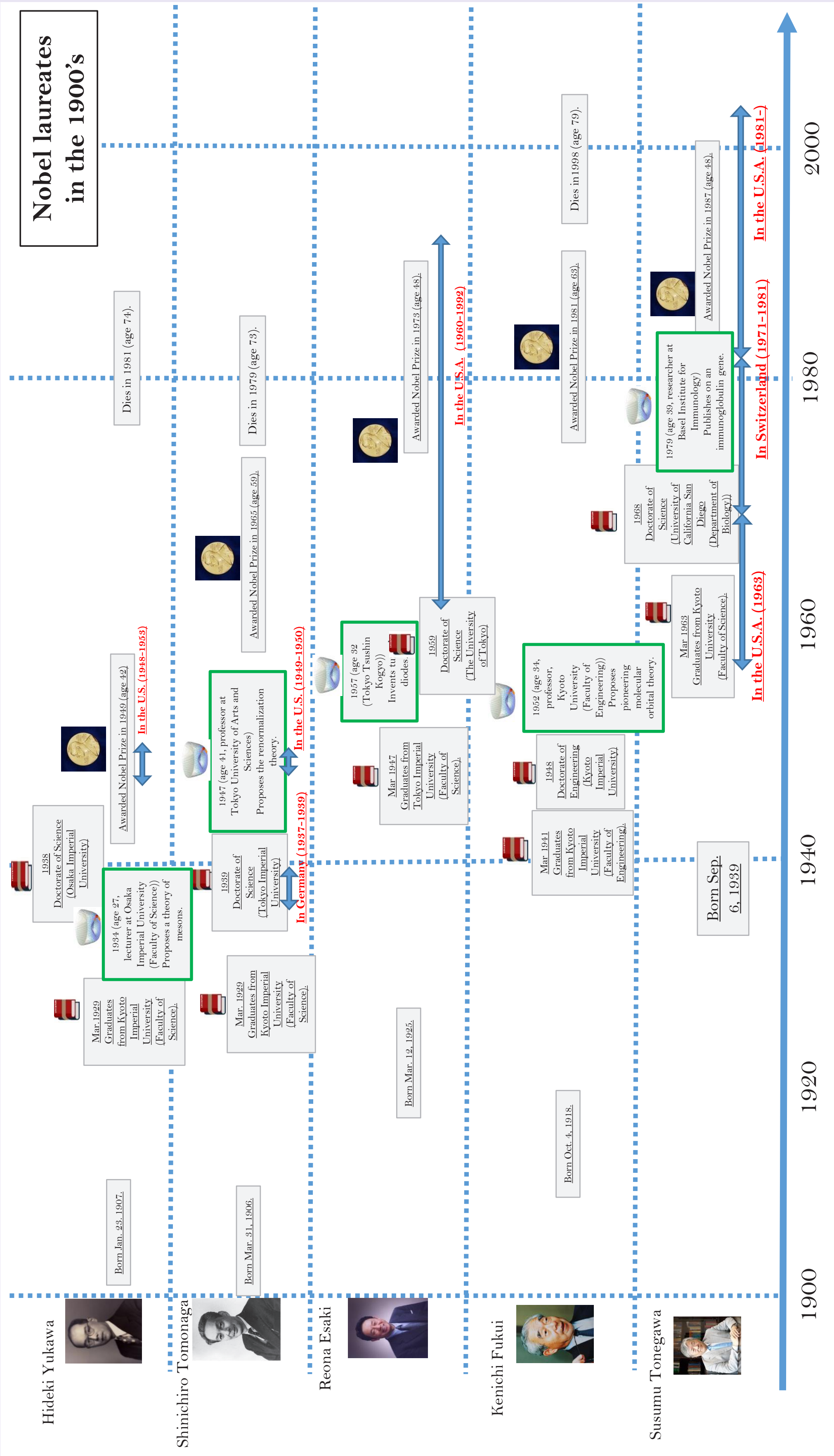
(3) The life courses of the Japanese Nobel laureates

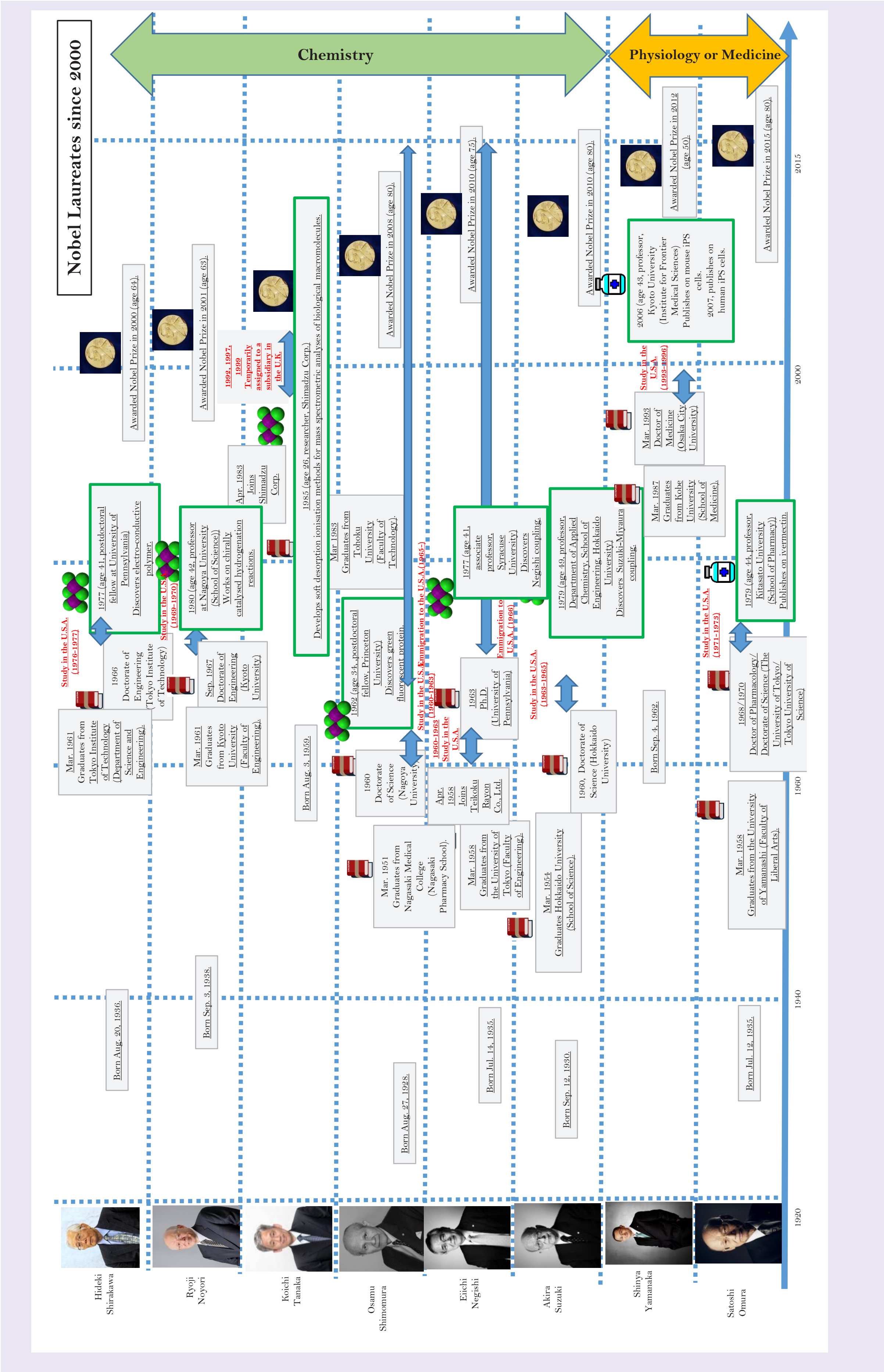
The winning of the Noble Prize is the result of the laureates' continuous efforts. It also shows the high standard of science and technology in Japan, given that, in the 21st century, Japan is the country with the second-most Nobel laureates. However, Japan faces a mountain of challenges in terms of its ability to achieve scientific and technological innovation: children's rejection of science, declines in enrollment for doctoral courses, declines in the international share of quality papers written by Japanese researchers, and the rapid progress of emerging economies, especially China. Due to these developments, there is the fear that Japan's status in the world of science and technology will fall.

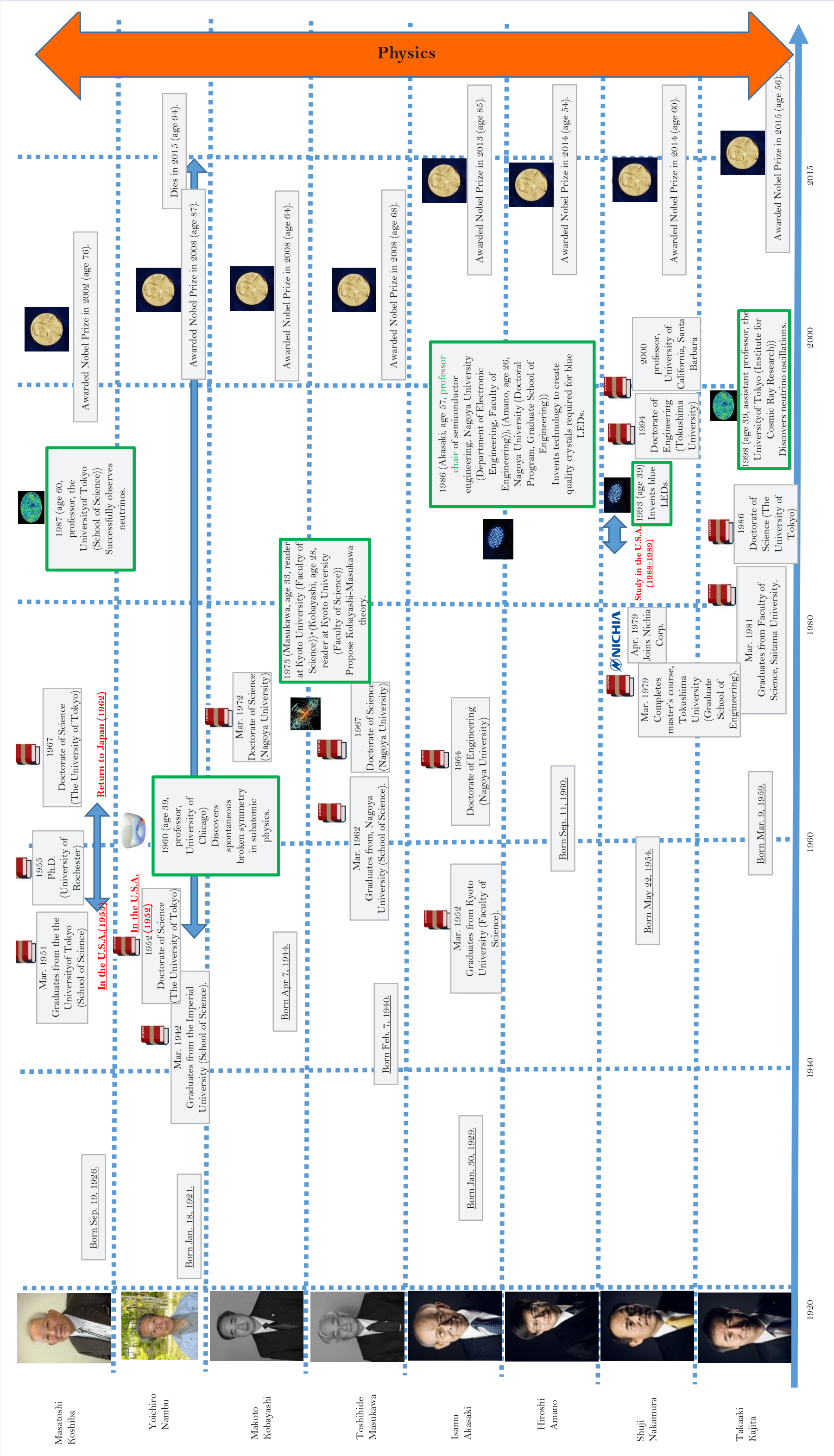
In light of the above, in order for Japan to continue to produce research achievements that might lead to a Nobel Prize, can we look to the lives of the Japanese Nobel laureates for ideas? Records of the Japanese Nobel laureates were compiled (Figure 4) and were examined in terms of several themes.

1 "Research that led to the Nobel Prize" refers to the research described as the prize motivation on the official website of the Nobel Foundation (http://www.nobelprize.org/).

■ Figure 4 Records of the Japanese Nobel laureates (in the three natural sciences).




Nobel Laureates since 2000
Chemistry
Physiology or Medicine
Hideki Shirakawa
Ryoji Noyori
Koichi Tanaka
Osamu Shimomura
Eiichi Negishi
Akira Suzuki
Shinya Yamanaka
Satoshi Omura
1920
1940
1960
2000
2015
Born Aug. 20, 1936.
Mar. 1961 Graduates from Tokyo Institute of Technology (Department of Science and Engineering).
1966 Doctorate of Engineering (Tokyo Institute of Technology)
Study in the U.S.A. (1976-1977)
1977 (age 41, postdoctoral fellow at University of Pennsylvania) Discovers electro-conductive polymer.
Awarded Nobel Prize in 2000 (age 64).
Born Sep. 3, 1938.
Mar. 1961 Graduates from Kyoto University (Faculty of Engineering).
Sep. 1967 Doctorate of Engineering (Kyoto University)
Study in the U.S.A. (1969-1970)
1980 (age 42, professor at Nagoya University (School of Science)) Works on chirally catalysed hydrogenation reactions.
Awarded Nobel Prize in 2001 (age 63).
Born Aug. 3, 1959.
Mar 1983 Graduates from Tohoku University (Faculty of Technology).
Apr. 1983 Joins Shimadzu Corp.
1985 (age 26, researcher, Shimadzu Corp.) Develops soft desorption ionisation methods for mass spectrometric analyses of biological macromolecules.
1992, 1997, 1999 Temporarily assigned to a subsidiary in the U.K.
Awarded Nobel Prize in 2002 (age 43).
Born Aug. 27, 1928.
Mar. 1951 Graduates from Nagasaki Medical College (Nagasaki Pharmacy School).
1960 Doctorate of Science (Nagoya University)
1960-1963 Study in the U.S.A.
1962 (age 34, postdoctoral fellow, Princeton University) Discovers green fluorescent protein.
Study in the U.S.A. Emmigration to the U.S.A. (1965-)
Awarded Nobel Prize in 2008 (age 80).
Born Jul. 14, 1935.
Mar. 1958 Graduates from the University of Tokyo (Faculty of Engineering).
Apr. 1958 Joins Teikoku Rayon Co., Ltd.
(1960-1963)
1963 Ph.D. (University of Pennsylvania)
Emmigration to U.S.A. (1966)
1977 (age 41, associate professor, Syracuse University) Discovers Negishi coupling.
Awarded Nobel Prize in 2010 (age 75).
Born Sep. 12, 1930.
Mar. 1954 Graduates Hokkaido University (School of Science).
1960, Doctorate of Science (Hokkaido University)
Study in the U.S.A. (1963-1965)
1979 (age 49, professor, Department of Applied Chemistry, School of Engineering, Hokkaido University) Discovers Suzuki-Miyaura coupling.
Awarded Nobel Prize in 2010 (age 80).
Born Sep. 4, 1962.
Mar. 1987 Graduates from Kobe University (School of Medicine).
Mar. 1993 Doctor of Medicine (Osaka City University)
Study in the U.S.A. (1993-1996)
2006 (age 43, professor, Kyoto University (Institute for Frontier Medical Sciences) Publishes on mouse iPS cells. 2007, publishes on human iPS cells.
Awarded Nobel Prize in 2012 (age 50).
Born Jul. 12, 1935.
Mar. 1958 Graduates from the University of Yamanashi (Faculty of Liberal Arts).
1968/1970 Doctor of Pharmacology/ Doctorate of Science (The University of Tokyo/ Tokyo University of Science)
Study in the U.S.A. (1971-1973)
1979 (age 44, professor, Kitasato University (School of Pharmacy)) Publishes on ivermectin.
Awarded Nobel Prize in 2015 (age 80).



Note: For Japanese Nobel laureates in natural sciences, the years of the following were investigated: birth, graduation from university, acquisition of doctorate, research achievements that led to the Nobel Prize, study overseas, and Nobel Prize win.

Data were compiled by the MEXT, NISTEP and SciREX Center at the National Graduate Institute for Policy Studies.

① Catalysts for interest in science

There are concerns over children's rejection of the sciences. This ongoing trend was shown in the National Assessment of Academic Ability published in August 2015 by MEXT. For example, 66.9% of the third-year junior high school students surveyed reported understanding their science classes very well (64.7% in the survey for the 2012 academic year). This figure is the lowest among the three subjects of Japanese, mathematics, and sciences. That 66.9% is 21.0 percentage points lower than the percentage of sixth-year elementary school students who gave that answer to the same question (the difference was 21.3 percentage points in the survey of the 2012 academic year). The difference between the third-year junior high school students and the sixth-year elementary school students is greater than those for Japanese classes (7.6 percentage points) and arithmetic/other math classes (9.3 percentage points). (In the survey of the 2012 academic year, the differences for Japanese classes and arithmetic/mathematics classes were 11.5 percentage points and 13.3 percentage points, respectively.)

What about the period between elementary school and high school for the Nobel laureates? Did they enjoy and excel in science and arithmetic or other math? If they excelled at these, how did they come to like them? That will be examined based on statements and biographies of the Nobel laureates and other materials.

■ Table 4 Catalysts for the Nobel laureates' interest in science[1] (examples)

Nobel Laureate	Catalysts for Interest in Science
Dr. Hideki Shirakawa	When making a fire to cook rice or to heat the bath, Dr. Shirakawa noticed that the flame was a different color from usual when he used a sheet of newspaper that had absorbed salt water.
Dr. Ryoji Noyori	In the fifth grade, Dr. Noyori was strongly impressed by Dr. Yukawa's Nobel Prize.
Dr. Koichi Tanaka	Scientific experimentation during his elementary school days was the catalyst.
Dr. Osamu Shimomura	From his elementary school days, Dr. Shimomura had been interested in the mechanisms of machines.
Dr. Eiichi Negishi	In his high school days, Dr. Negishi liked physics, math, and most of all, geometry.
Dr. Akira Suzuki	Dr. Suzuki likes to know what is new in math and science.
Dr. Shinya Yamanaka	Dr. Yamanaka was inspired by his father, who was an engineer at a small factory that manufactured parts for sewing machines.
Dr. Satoshi Omura	Appreciating nature with his father gave Dr. Omura an inquiring mind for the unknown.
Dr. Masatoshi Koshiba	Dr. Koshiba was strongly impressed by Dr. Yukawa's Nobel Prize.
Dr. Yoichiro Nambu	Dr. Nambu was strongly impressed by Dr. Yukawa's Nobel Prize.
Dr. Makoto Kobayashi	Dr. Kobayashi was influenced by the Sakata model*, which he came to know of when he was in high school.
Dr. Toshihide Masukawa	Dr. Masukawa was influenced by the Sakata model*, which he came to know of when he was in high school..
Dr. Isamu Akasaki	Dr. Akasaki was fascinated by specimens of minerals as a child.
Dr. Hiroshi Amano	Dr. Amano became interested in the mechanism of an electric fan when he was in elementary school.
Dr. Shuji Nakamura	Dr. Nakamura liked math and physics and loved experiments from his junior high school days.
Dr. Takaaki Kajita	What he heard from his teacher in physics at his high school days gave Dr. Kajita an interest in physics.

*This model proposes that the hadron, which is a fundamental particle of matter in space, is composed of protons, neutrons, and lambda baryons, and antiparticles of all of these.

Source: MEXT

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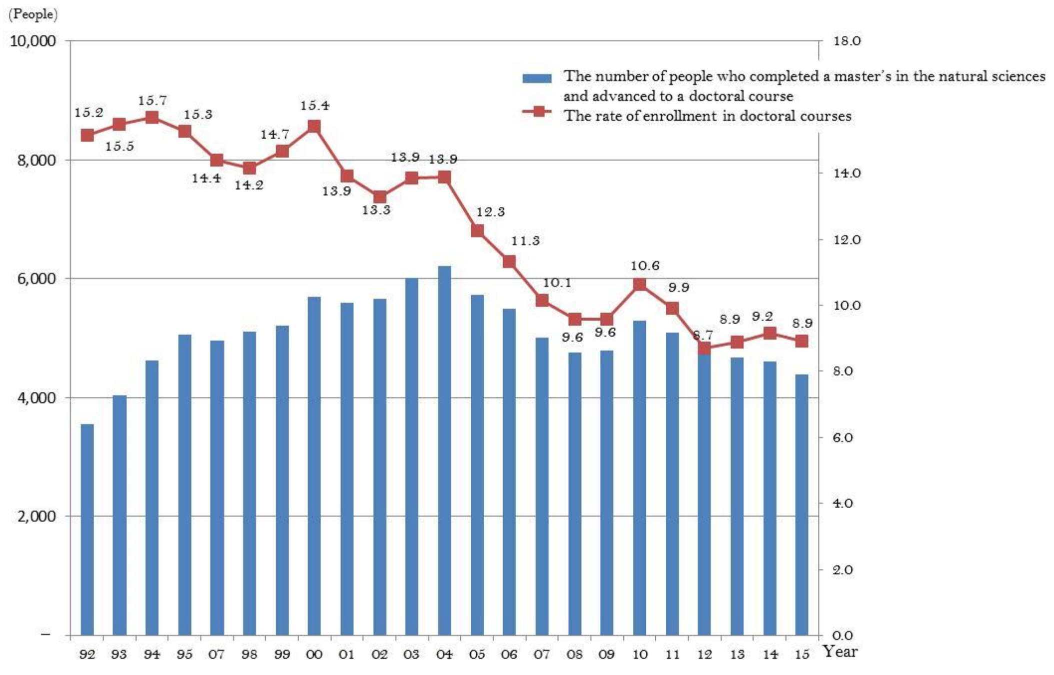
1 Sources for each laureate in Tables 4 to 8 are the following.
For Dr. Shirakawa: National Museum of Nature and Science. "Great Achievements by 9 Nobel Laureates in the Sciences." http://www.kahaku.go.jp/exhibitions/tour/nobel/shirakawa/p1.html
For Dr. Noyori: National Museum of Nature and Science. "Great Achievements by 9 Nobel Laureates in the Sciences." http://www.kahaku.go.jp/exhibitions/tour/nobel/shirakawa/p1.html
For Dr. Tanaka: The elementary school homeroom teacher of Tanaka. "The Personality of Koichi Tanaka." *Bunseki.* The Japan Society for Analytical Chemistry. Tohoku University. "The Honorable Trajectory of Koichi Tanaka" (http://www.bureau.tohoku.ac.jp/manabi/manabi22/mm22-45.htm
For Dr. Shimomura: Shimomura, Osamu. *Learning from Jellyfish.* Nagasakibunkensha, 2010.
For Dr. Negishi: Negishi, Eiichi. *Keep your dreams alive! A message from Nobel laureate Eiichi Negishi.* Kyodo News, 2010.
For Dr. Suzuki: Suzuki, Akira supervisor. Hokkaidoshimbunsha ed. *The chemical reaction that changed the world: Akira Suzuki and the Nobel Prize.* The Hokkaido Shimbun Press, 2011. CoSTEP at Hokkaido University. "Akira Suzuki: The road to the Nobel Prize in chemistry." http://costep.hucc.hokudai.ac.jp/ebooks/suzuki2010/
For Dr. Yamanaka: Yamanaka, Shinya and Shinya Midori (interviewer). *Interview with Dr. Shinya Yamanaka on his life and iPS cells.* Kodansha, 2012.
For Dr. Omura: Rensei Baba. Satoshi Omura: *The chemist who protected 200 million people from disease.* Chuokoron-Shinsha Inc., 2012.
For Dr. Koshiba: Masatoshi Koshiba. *I wanted to be a physics man: The trajectory to the Nobel Prize in Physics.* The Asahi Shimbun Company, 2002.
For Dr. Kobayashi and Masukawa: Kobayashi, Makoto and Toshihide Masukawa. *Let's think about it together: inspirations for the Nobel Prize in Physics.* Asahi Shimbun Publications Inc., 2009.
For Dr. Nambu: Nambu, Yoichiro. Ezawa, Hiroshi ed. *Development of particle physic.* Iwanami Shoten, 2009.
For Dr. Akasaki: Akasaki, Isamu. *Enchanted by blue light: The story of the development of blue LEDs.* Nikkei Publishing Inc., 2013.
For Dr. Amano: Amano, Hiroshi and Hironobu Fukuda. *Professor Amano's 'the world of blue LEDs': From the principle of glowing to state-of-the-art application.* Kodansha, 2015.
For Dr. Nakamura: Benesse educational information website. "From Scientist Shuji Nakamura to those who have advanced a grade." http://benesse.jp/juken/201504/20150409-1.html
Nakamura, Shuji. *Indignation and breakthrough: Once common sense was abandoned, the blue light came into view.* Home-sha Inc., 2001.
For Dr. Kajita: Kajita, Takaaki. *Probe into space and elementary particles through neutrinos.* Heibonsha, 2015.
Takarajimasha, Inc. *Satoshi Omura and Takaaki Kajita: Ways of living as Nobel Laureates.* Takarajimasha, Inc., 2016.

Table 4 shows examples of catalysts that prompted Nobel laureates' interest in science. The examples were collected from literature on Nobel laureates. Many of the Nobel laureates seem to have been interested in making things, conducting experiments, and learning about natural mechanisms ever since they were small. As is seen in the cases of Dr. Tanaka and Dr. Kajita, some of the laureates became interested in science through school. In other cases, like Dr. Koshiba's, Dr. Noyori's and Dr. Nambu's, they were significantly influenced by the Japanese Nobel laureates who preceded them.

② Reasons for advancement to higher institutions for the purpose of majoring in sciences and for setting their sights on being a researcher

There are concerns not only over children's rejection of science but also over the decline in the number of students who set their sights on being researchers. The population of 18-year-olds was around 1.2 million in fiscal 2015. That figure is expected to be below 1 million in fiscal 2031. In light of this, enrollment in doctoral courses has been declining, and this has raised concerns about a shortage of human resources who might support science and technology in Japan in the future (Figure 5). With these situations in mind, let us look at why Japanese Nobel laureates aimed to advance to higher institutions for the purpose of majoring in sciences and to set their sights on being researchers.

■ Figure 5 Changes in the number of people who completed a master's in the natural sciences and advanced to a doctoral course, and changes in the rate of enrollment in doctoral courses



Source: MEXT

■ Table 5 Nobel laureates' reasons for advancing to higher institutions for the purpose of majoring in sciences and for setting their sights on being researchers

Nobel Laureate	Motivation for Advancing to Higher Education to Major In Science (upper column) / Motivation for Becoming a Researcher (lower column)
Dr. Hideki Shirakawa	From his junior high school days, Dr. Shirakawa wanted to study science and physics at university to produce new plastics.
	Dr. Shirakawa passed the entrance examination of the Department of Science and Engineering at Tokyo Institute of Technology where he would be able to study in three areas, including chemistry and engineering.
Dr. Ryoji Noyori	Dr. Noyori became interested in petrochemistry when he came to know that nylon was made from water, coal and air, and he enrolled in the faculty of engineering.
	Dr. Noyori was aiming to enter industry after graduation, but his teacher advised him to remain at university.
Dr. Koichi Tanaka	Scientific experiments in his elementary school days had an impact on Dr. Tanaka..
	The academic culture at his university made Tanaka learn to value studies that contribute to practical learning. (Dr. Tanaka joined a laboratory run by a business.)
Dr. Osamu Shimomura	Dr. Shimomura followed the advice of his teacher.
	In a job interview, the interviewee advised Dr. Shimomura to become a researcher.
Dr. Eiichi Negishi	Dr. Neghishi chose to pursue applied science because that field offered stable job opportunities at that time.
	After joining a business, Dr. Negishi's awareness of academic research increased and he went abroad to study at a university. His eyes were opened to the joy of searching for truth.
Dr. Akira Suzuki	Dr. Suzuki excelled at math, physics, and chemistry.
	After reading the *Textbook of Organic Chemistry* by L. F. Fieser and M. Fieser of Harvard University, Dr. Suzuki became interested in organic chemistry.
Dr. Shinya Yamanaka	Dr. Yamanaka liked math and physics, and he had a strong aspiration for research from the beginning.
	Dr. Yamanaka enrolled in a school of medicine to be a clinician. Later he aimed to pursue basic medicine to find ways of treating patients suffering from intractable diseases that could not be cured by modern medicine.
Dr. Satoshi Omura	As a high school student, Dr. Omura came to prefer science.
	From his first year at university, Dr. Omura was free to perform the experiments he wanted with assistants and university-mates who were his senior.
Dr. Masatoshi Koshiba	When he was in high school, Dr. Koshiba heard his physics teacher say he was not cut out for physics. The remark prompted him to enroll in university to major in physics.
	Finding a job was difficult at that time.
Dr. Yoichiro Nambu	Two great physicists who contributed to the solution for the basics of particle physics influenced Dr. Nambu.
	Same as above.
Dr. Makoto Kobayashi	As a high school student, Kobayashi read *The Evolution of Physics*, a book that explained physics,.
	In choosing from theoretical courses at graduate school, Dr. Kobayashi decided to join Professor Sakata's lab.
Dr. Toshihide Masukawa	Dr. Masukawa was inspired by the Sakata model, which he came to know of when he was in high school.
	Among courses for theories at graduate school, Dr. Masukawa chose to join Professor Sakata's lab.
Dr. Isamu Akasaki	From his elementary school days to his high school days, Dr. Akasaki always liked math and other subjects related to science.
	When Dr. Akasaki was working at a company, his boss was recruited by a university to the position of professor, and Dr. Akasaki followed that boss to the university.
Dr. Hiroshi Amano	Dr. Amano liked ham radios.
	Dr. Amano does not think he has ever aimed to be a researcher.
Dr. Shuji Nakamura	Dr. Nakamura aspired to be a scientist able to create robots or other equipment useful to people.
	It became impossible for Dr. Nakamura to manufacture things at a business for which he worked.
Dr. Takaaki Kajita	Understanding things by understanding principles fascinated Dr. Kajita.
	Dr. Kajita entered the graduate school of the University of Tokyo and became involved in experiments using the Kamiokande (KAMIOKA Nucleon Decay Experiment) water Cherenkov detector.

Source: MEXT

Table 5 shows that many of the Nobel laureates have liked or have found fun in the natural sciences and that this was why they advanced to higher institutions to major in sciences.

Motivations for becoming researchers differed from laureate to laureate. Some of the laureates, including Dr. Nambu, were impressed by great researchers such as Yukawa and set their sights on being researchers. Some had already decided to enter research when they chose a laboratory at graduate school. Dr. Tanaka's case contrasts with Dr. Negishi's case. Dr. Tanaka placed high value on practical learning when he was at university and aimed to be a researcher at a private company. In contrast, Dr. Negishi joined a private company after graduating from university. When he was studying at a university overseas, his eyes were opened to the joy of freely searching for truth, and he chose to move on to become a researcher at a university.

③ Ways leading to the research achievements that would end in a Nobel Prize

It has been pointed out that one of the reasons for the decline in enrollment in doctoral courses is the shortage of stable positions for young researchers who have completed their doctoral courses. There is also the concern that the shortage may be adversely affecting the research environment for young researchers who want to settle down to engage in research that might lead to a Nobel Prize. How did the Nobel laureates spend their days as young researchers?

(i) From university to graduate school

Some of the Nobel laureates enrolled in a graduate school at a university different from their undergraduate university. After graduating from the Faculty of Liberal Arts at the University of Yamanashi, Dr. Omura enrolled in a graduate school at Tokyo University of Science thanks to an introduction by his teacher. Dr. Kajita wanted to conduct tests relating to elementary particles and enrolled in a graduate school at the University of Tokyo after graduating from Saitama University. Dr. Koshiba spent several months studying hard in a theoretical physics lab at Osaka City University when he was in a master's course at the University of Tokyo. The lab had just been opened by Dr. Nambu, whom Dr. Koshiba respected as a theoretical physicist. Dr. Shimomura spent a year away from Nagasaki University studying at Nagoya University and began full-scale research on a theme that would lead to his Nobel Prize. Dr. Yamanaka enrolled in a school of medicine at Kobe University to become a clinician. Later he hoped to change his field of study to basic medicine and enrolled in the Graduate School of Pharmacology at Osaka City University to find ways to treat patients suffering from intractable diseases that could not be cured by modern medicine. Besides, from the very beginning, he strongly aspired to be a researcher. When he was in graduate school at Osaka City University, he conducted experiments to confirm a hypothesis during his pharmacological studies. His results differed from the hypothesis and were completely unexpected. Dr. Yamanaka said that, through experiences such as this one, he was able to learn the following lessons: Science is full of wonder, and the fun in science is to encounter unexpected results.

(ii) Career paths after graduation from university or graduate school

Looking at the career paths of Nobel laureates after their graduation from undergraduate university or graduate school, one finds that 12 laureates chose to study in academia, including at university. Akasaki, Dr. Nakamura, Dr. Tanaka, and Dr. Negishi chose to join private companies.

■ Table 6 Facts about Nobel laureates, including ages at which they obtained a position that was without a time limit

Nobel Laureate	Academic degree (univ. and year of conferral, and researcher's age at conferral)	Position, institution and age at which the researcher gained a non-fixed-term position
Dr. Hideki Shirakawa	Ph.D. (Tokyo Institute of Technology, 1966, age 30)	Assistant, Tokyo Institute of Technology, after completing the doctoral course there at 29
Dr. Ryoji Noyori	Ph.D. (Kyoto University, 1967, age 29)	Assistant, Kyoto University, after completing the master's course there at 24
Dr. Koichi Tanaka	Bachelor of Engineering (Tohoku University, 1983, age 23)	Company employee, Central Research Laboratory of Shimadzu Corporation, 23
Dr. Osamu Shimomura	Ph.D. (Nagoya University, 1960, age 32)	Assistant, Nagasaki University, 29
Dr. Eiichi Negishi	Ph.D. (University of Pennsylvania, 1963, age 28)	Company employee, central research laboratory of Teijin Ltd., 22; assistant, Purdue University, 32.
Dr. Akira Suzuki	Ph.D. (Hokkaido University, 1960, age 29)	Assistant, Hokkaido University, after completing the doctoral course there, 28
Dr. Shinya Yamanaka	Ph.D. (Osaka City University, 1993, age31)	Assistant, Osaka City University, 34
Dr. Satoshi Omura	Ph.D. (University of Tokyo, 1968, age 33 Tokyo University of Science, 1970, age 35)	Assistant, University of Yamanashi at 27
Dr. Masatoshi Koshiba	Ph.D. (University of Tokyo, 1967, age 41)	Associate professor, University of Tokyo, 31
Dr. Yoichiro Nambu	Ph.D. (University of Tokyo, 1952, age 31)	Assistant, University of Tokyo, 28
Dr. Makoto Kobayashi	Ph.D. (Nagoya University, 1972, age 27)	Assistant, Kyoto University, after completing the doctor's course at Nagoya University, 27
Dr. Toshihide Masukawa	Ph.D. (Nagoya University, 1967, age 27)	Assistant, Kyoto University, after completing the doctor's course at Nagoya University, 30
Dr. Isamu Akasaki	PhD (Nagoya University, 1964, age 35)	Company employee. Kobe Kogyo Corporation, 23; assistant, Nagoya University, 30
Dr. Hiroshi Amano	Ph.D. (Nagoya University, 1989, age 29)	Assistant, Nagoya University, 27
Dr. Shuji Nakamura	Ph.D. (Tokushima University, 1994, age 40)	Company employee, Nichia Corporation, 24
Dr. Takaaki Kajita	Ph.D. (University of Tokyo, 1986, age 27)	Assistant, University of Tokyo, after completing the doctoral course there, 24

Source: MEXT

Table 6 shows that all of the Noble laureates obtained stable positions when they were in their 20's or 30's, which means that they were in an environment where they could settle down to study while they were still young.

(iii) Research histories of the Nobel laureates leading up to their Nobel win

Table 7 shows that, in not a few cases, as young researchers, the Nobel laureates conducted research that directly led to their prize. For example, when Dr. Kobayashi and Dr. Masukawa were assistants at Kyoto University at the ages of 28 and 33, respectively, they presented the Kobayashi- Masukawa theory, which would eventually earn them the Nobel Prize. In his doctoral course at the age of 26,[1] Dr. Amano, along with his Ph.D. advisor Dr. Akasaki, became the first in the world to grow high-quality, high-purity GaN crystals using low-temperature deposited buffer layer MOCVD technology, a method they invented.

When they were young, some of the laureates began to realize research achievements that did not directly relate to the Nobel Prize but were a foundation for research that would later bring them the prize. For example, when he was studying at Nagoya University, not the university he initially enrolled in, Dr. Shimomura conducted research on luciferin, the light-emitting material discharged by the *Vargula hilgendorfii* crustacean. The research was on bioluminescence, which would later lead to the discoveries of aequorin and green fluorescent protein (GFP).

As seen above, as young researchers, not a few Nobel laureates produced research achievements that would lead to their Nobel Prize.

1 MOCVD: Metal organic chemical vapor deposition is a method for growing crystals by injecting gases so as to cause substances to deposit on heated substrates.

■ Table 7 Nobel laureates' research activities before their Nobel Prize win

Nobel laureate	Research environments until being awarded the Nobel Prize (upper column) / Age at which research achievements which led to the Nobel Prize were produced and the post of the laureate at the time
Dr. Hideki Shirakawa	While working as an assistant at the Chemical Resources Laboratory of the Tokyo Institute of Technology, Shirakawa continued his research. When he was in the US and was conducting joint research, he developed electric conductive plastic.
	Age 41, postdoctoral fellow at the University of Pennsylvania
Dr. Ryoji Noyori	Noyori developed asymmetric synthetic reactions while conducting research throughout his career as follows: instructor at Kyoto University, associate professor at Nagoya University, and professor at Nagoya University after he studied in the U.S.
	Age 42, professor of School of Science at Nagoya University
Dr. Koichi Tanaka	Tanaka engaged in developing equipment for mass spectrometry at a research laboratory of the company he worked for. He found by chance a method that enabled the mass spectrometry of biological macromolecules.
	Age 26, researcher at Shimadzu Corp.
Dr. Osamu Shimomura	At Nagoya University (where he was studying away from the university to which he belonged), Shimomura conducted research on luciferin that would later lead to the discovery of aequorin and green fluorescent protein (GFP). When he was studying in the US later, he discovered aequorin and GFP.
	Age 34, postdoctoral fellow at Princeton University
Dr. Eiichi Negishi	Upon graduating from the University of Tokyo, he joined Teikoku Rayon Co., Ltd. (currently Teijin Ltd.). Two years later, he went to the U.S. as a Fulbright scholar. He was stimulated by research at the university in the U.S. and left the company. He again went to the U.S. as a postdoctoral researcher and in 1979 conducted research on organic boron compounds under Professor Herbert C. Brown of Purdue University. Then he moved to Syracuse University and discovered the Negishi cross-coupling reaction.
	Age 41, associate professor at Syracuse University.
Dr. Akira Suzuki	When he was an associate professor in the Faculty of Engineering at Hokkaido University, Suzuki read *Hydroboration* written by Professor Herbert C. Brown of Purdue University. Later he began research on boron compounds. He was so impressed by the book that he went to the U.S. as a postdoctoral research associate in Professor Brown's laboratory. After returning to Japan, he discovered the Suzuki-coupling reaction. It has been utilized in many fields in society, such as for medical products, pesticides, liquid crystals and light-emitting diodes.
	Age 49, professor in the Department of Applied Chemistry of the Faculty of Engineering at Hokkaido University
Dr. Shinya Yamanaka	Yamanaka went to the U.S. to study as a post-doc. At that time his research theme was not pluripotent stem cells such as iPS cells or induced pluripotent stem cells. After returning to Japan, he pursued research he had been doing in the US, and he became interested in embryo stem cells (ES cells). Then he moved to the Nara Institute of Science and Technology, where he set a clear goal of producing cells similar to ES cells from somatic cells without using human embryos. He succeeded in generating iPS cells.
	Age 43, professor at Institute for Frontier Medical Sciences at Kyoto University
Dr. Satoshi Omura	Omura once was a high school teacher before he aimed to be a researcher, and he became an assistant at a university. After he transfered to Kitasato University, he went to the US where he enjoyed a research environment in which he could pursue what he wanted to study as much as possible. He continued his research after returning to Japan and discovered a new therapeutic method for infections caused by roundworms.
	Age 44, professor in the School of Pharmacy at Kitasato University
Dr. Masatoshi Koshiba	In his master's course, Koshiba studied hard at Professor Nambu's lab in Osaka City University, away from the graduate school he was enrolled in. Then Professor Fujimoto invited him to conduct experiments on cosmic rays using nuclear emulsion plates. In his doctoral course, he went to the U.S., where the research environment, including facilities and equipment, were far better than those in Japan. After returning to Japan, he worked for the Institute of Nuclear Study, University of Tokyo. He again left for the U.S. and engaged in research on cosmic rays. The experience of learning from astronomers at that time led him to being awarded the Noble Prize later.
	Age 60, professor in the School of Science at the University of Tokyo
Dr. Yoichiro Nambu	Conducting joint research at Osaka City University, Nambu developed a theory about the paired generation of strange particles that had newly appeared. His achievements were recognized, and he went to study at the Institute for Advanced Study in Princeton, U.S.
	Age 39, professor at the University of Chicago
Dr. Makoto Kobayashi	When he was 28 and an assistant at Kyoto University, Kobayashi proposed the Kobayashi-Masukawa theory. The achievement brought him the Nobel Prize.
	Age 28, assistant at Kyoto University
Dr. Toshihide Masukawa	When he was 33 and an assistant at Kyoto University, Kobayashi proposed the Kobayashi-Masukawa theory. The achievement brought him the Nobel Prize.
	Age 33, assistant at Kyoto University
Dr. Isamu Akasaki	Akasaki joined Kobe Kogyo Corp. When his boss moved to Nagoya University, he also moved there as an assistant. At Nagoya University, research on semiconductors had just begun, and the research environment was not sufficient.
	Age 57, chair of semiconductor engineering, Department of Electronic Engineering of the Faculty of Engineering at Nagoya University
Dr. Hiroshi Amano	In his doctoral course, Amano succeeded in generating quality GaN crystals with high purity with his Ph.D. advisor, Akasaki. When he was an assistant, he succeeded in creating the world first high-brightness blue LED crystals.
	Age 26, Doctoral Program of the Graduate School of Engineering at Nagoya University
Dr. Shuji Nakamura	In the research lab of a company, Nakamura started to research and develop blue LEDs in 1989. He invented high-brightness blue LEDs in 1993.
	Age 39, researcher at Nichia Corp.
Dr. Takaaki Kajita	After obtaining his doctorate, Kajita was not accepted as a postdoctoral fellow by the Japan Society for the Promotion of Science. He worked for the International Center for Elementary Particle Physics (ICEPP) as an assistant for 2 years before he was hired as an assistant at the Institute for Cosmic Ray Research. During these years, he was a central figure is experiments using two water Cherenkov detectors: the Kamiokande (KAMIOKA Nucleon Decay Experiment) and the Super-Kamiokande.
	Age 39, associate professor at Institute for Cosmic Ray Research of the University of Tokyo

Source: MEXT

④ Study abroad and/or other international experience

Some of the causes of the decline in the international share of quality papers written by Japanese researchers are the decline in the share of Japanese researchers listed as authors on international collaborative papers and the lowering of Japan's status in international networks of academic research. It is said that behind these trends is the inward-looking nature of young researchers, that is, young researchers are hesitant about studying or doing research overseas because they worry about what will happen when they return to Japan, including whether they will be able to find a good position. Let us look at the overseas research experience of Japanese Nobel laureates.

■ Table 8 Nobel laureates' motivations for, and achievements from, studying abroad

Nobel Laureate	Study and/or other experience abroad (motivations and achievements)	Time and situation
Dr. Hideki Shirakawa	・Dr. Shirakawa went to the U.S.A. in response to the request for joint research by the University of Pennsylvania. ・He developed electro conductive plastics.	1976-1977 Study in the U.S.A.
Dr. Ryoji Noyori	・Dr. Noyori went to study at Harvard University, as he had hoped. ・He deepened ties with people who would later be awarded Nobel Prizes.	1969-1970 Study in the U.S.A.
Dr. Koichi Tanaka	(After achieving results that would lead to the Nobel Prize, Tanaka was temporarily sent to a subsidiary overseas.)	1992, 1997, 1999 Work at a subsidiary in the UK
Dr. Osamu Shimomura	・Shimomura was invited by Princeton University. ・He discovered aequorin and GFP in research while in the U.S.A.	1965- Emigration to the U.S.A..
Dr. Eiichi Negishi	・Dr. Negishi went to study at the University of Pennsylvania because his awareness of pursuing academic research increased and Teikoku Rayon Co., Ltd. (currently Teijin Ltd.), the company he worked for, had the corporate culture of encouraging its employees to look overseas. ・He discovered "the Negishi cross-coupling reaction" as a result of research at Purdue University and Syracuse University.	1960-1963 Study in the U.S.A. 1965- Emigration to the U.S.A.
Dr. Akira Suzuki	・Suzuki was advised by a professor in the Faculty of Engineering to study abroad, and he went to Purdue University. ・After returning to Japan, he developed the research on organic boron compounds he had conducted at Purdue University to create Suzuki cross-coupling.	1963-1965 Study in the U.S.A.
Dr. Shinya Yamanaka	・Dr. Yamanaka went to Gladstone Institutes to learn research methods for making knockout mice. ・Back in Japan, while continuing the research he had done in the U.S.A., he became interested in pluripotent stem cells such as embryonic stem cells. He developed his interests into research that would later result in iPS cells.	1993-1996 Study in the U.S.A.
Dr. Satoshi Omura	・Dr. Omura was advised by his father and his senior researchers to go abroad to study. He went to Wesleyan University. ・Through joint research with MSD, he succeeded in research and development of ivermectin.	1971-1973 Study in the U.S.A.
Dr. Masatoshi Koshiba	・Following the failure of experiments using nuclear emulsion plates, Koshiba decided to study at the center of this kind of research. He went to the University of Rochester. ・During as second stay in the U.S.A., this time at the University of Chicago, he learned from astronomers about stars, including supernovas. This experience led him to be awarded the Nobel Prize later.	1953-1962 Study in the U.S.A.
Dr. Yoichiro Nambu	・As a result of the recognition of achievements of joint research at Osaka City University, Nambu went to the Institute for Advanced Study in Princeton.	1952- Study in the U.S.A.
Dr. Makoto Kobayashi	None	--
Dr. Toshihide Masukawa	None	--
Dr. Isamu Akasaki	None	--
Dr. Hiroshi Amano	None	--
Dr. Shuji Nakamura	・Dr. Nakamura went to the University of Florida to learn MOCVD. ・Returning to Japan, he started modifying MOCVD equipment.	1988-1989 Study in the U.S.A.

Source: MEXT

Table 8 shows that 11 Nobel laureates have studied or researched overseas. Seven laureates (Dr. Nambu, Dr. Shirakawa, Dr. Noyori, Dr. Shimomura, Dr. Suzuki, Dr. Yamanaka, and Dr. Omura) studied or researched abroad after they acquired their doctorate. Dr. Tanaka, Dr. Negishi, and Dr. Nakamura joined private companies before they went abroad to study or for other reasons.

Catalysts and motivations for studying abroad vary. In some cases, what the Nobelist achieved while studying overseas directly led to their prize. Dr. Shirakawa was accepted as a research associate at the Chemical Resources Laboratory, Tokyo Institute of Technology in 1966 soon after he completed his doctoral course. He was conducting research on organic polymer chemistry when Professor Alan MacDiarmid of the University of Pennsylvania, who had become interested in Dr. Shirakawa's research on polyacetylene, invited him to work with him. Dr. Shirakawa went to the U.S.A. as a post-doctoral fellow in 1976. There, with Professors Alan MacDiarmid and Alan Heeger, he succeeded in developing the conductive plastic that would bring him the Nobel Prize. The achievement was the result of interdisciplinary research: Dr. Shirakawa's organic chemistry, Professor Alan MacDiarmid's inorganic chemistry, and Professor Alan Heeger's physics. Dr. Shimomura worked on bioluminescence at Nagasaki University and Nagoya University. At Princeton University, he discovered aequorin and GFP through research on the luminescent material of Aequorea jellyfish.

For many of the laureates, their experience of studying abroad greatly influenced the research that would lead to their Nobel Prize. After returning to Japan, Dr. Suzuki developed Suzuki cross-coupling by expanding on his research on organic boron compounds that he had conducted under Professor Herbert Brown at Purdue University. While he was studying at Wesleyan University, Dr. Omura had the opportunity to begin joint research with Merck Sharp & Dohme and he succeeded in R&D on ivermectin through the joint research.

Dr. Yamanaka and Dr. Nakamura studied abroad to learn in a country where leading-edge studies in their fields were being conducted. Dr. Yamanaka went to learn about knockout mice, and Dr. Nakamura went to learn about MOCVD equipment for growing crystalline layers. Their experience of studying abroad turned out to have significant influence on producing research achievements that would lead to their Nobel Prizes. Dr. Yamanaka said that his eyes were opened through these experiences and through friendly competition with various researches, that the three years of studying abroad changed his way of thinking greatly, and that techniques, ways of thinking, and personal connections gained from studying abroad became the driving force behind the development of iPS cells.[1]

⑤ How did the Japanese government support research by Nobel laureates?

For Japan to continue to be a global front runner as "a creative science and technology nation," it must promote balanced R&D. It takes a long time for basic research to yield economic or social effects, and the achievements of basic research are difficult to link directly to those effects. Therefore, governmental support is imperative for basic research.

This section examines governmental support given to the Nobel laureates in the natural sciences since 2000[2].

Let us take Dr. Noyori's case as an example. The process of his research and related events that led to the Nobel Prize can be summarized as in Figure 6. As an instructor at Kyoto University in 1966, Dr. Noyori discovered asymmetric hydrogenation, which later led to the Nobel Prize[3], and with the continued support of Grants-in-Aid for Scientific Research, he developed a rhodium catalyst that contains a compound called

1 See the website of the United Japanese Researchers around the World (http://uja-info.org/findingourway/post/1055/).

2 The National Institute of Science and Technology Policy (NISTEP) of MEXT and the SciREX Center of the National Graduate Institute for Policy Studies received grants for their corporation in collecting information on the Nobel laureates (Grant-in-Aid for Scientific Research (C) for *Empirical Research through Analysis of the Nobel Prizes: Relationship between Knowledge Creation Process and Research Promotion Policy* Project/Area Number 24501092. Principal Investigator Shinichi Akaike.).

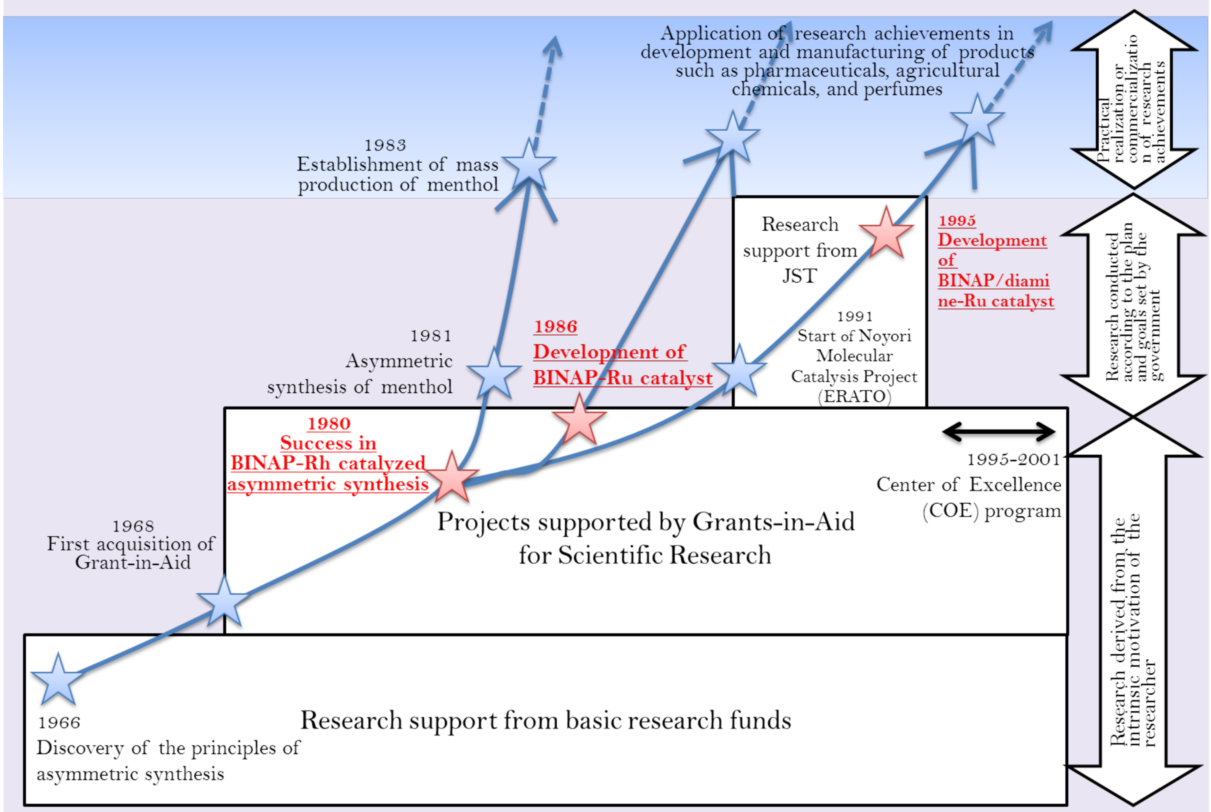
3 Some organic compounds are chiral, that is, with the same chemical formula but with difference in structure. The different structures are called enantiomers. The biochemical action significantly differs between the right-handed enantiomer and the left-handed enantiomer. In some cases, one enantiomer of a chemical compound might make a useful drug and the other enantiomer might be poisonous. Therefore in the field of medical products, use of only medicative enantiomers can be efficient. It had been difficult to produce single enantiomers, but asymmetric synthesis made it possible to selectively produce either of right-handed or left-handed compounds by design.

BINAP in 1980[1]. His research since 1986 has found a series of efficient methods for asymmetric hydrogenation of olefins and ketones using ruthenium catalyst. Four years of Grants-in-Aid for Scientific Research for Specially Promoted Research since 1987 were useful to these achievements. Then he achieved the asymmetric hydrogenation of simple ketones under the Dr. Noyori Molecular Catalysis Project of the Exploratory Research for Advanced Technology (ERATO) Program (currently the JST Strategic Basic Research Programs), a project that was implemented from 1991 onward.[2] After that, his research was supported by a Center of Excellence (COE) program and it produced results that enabled the industrial production of various useful substances, such as carbapenem antibiotics, antidepressants, sleep inducers, antimycotic agents, ceramides or intercellular lipids, and fragrance ingredients, as well as the antibiotic levofloxacin (marketed as Cravit). Dr. Noyori recalled in published materials that his long period of research life had been supported by grants-in-aid and that the fruits of his research would never have been obtained without administration by a director who was knowledgeable and had a sense of responsibility, which was representative of the JST Strategic Basic Research Programs.[3,4] His remarks indicate the importance of tailoring government assistance to the motivations and nature of the research.

In 1983, only 3 years after the development of BINAP, the industrial production of menthol was realized by Takasago International Corporation, a fragrance manufacturer. This was the result of industry-university-government joint research on asymmetric synthesis of menthol conducted from 1981, the year after BINAP was developed. In an interview, Dr. Noyori recalled[5] having many friends in industry, and it was agreed that BINAP could be utilized. He says joint research then started from the early stage for production. The innovation needed for the future of a company depends on the determination of the leader, he adds. His remarks suggest the importance of industry-academia joint research and the strong presence of small- and medium-sized enterprises and venture companies.

1 The development of BINAP made it possible to produce single enantiomers at a rate of almost 100%.
2 Traditional methods of asymmetric hydrogenation use atoms or atomic groups such as oxygens, nitrogens, and halogens which exist in the neighboring area of C-C double bonds and C-O double bonds in organic molecules. Simple ketones do not have these structures, so the asymmetric hydrogenation of simple ketones was difficult.
3 *Japanese Scientific Monthly*, October 2006. Japan Society for the Promotion of Science.
4 Noyori, Ryoji. *My Résumé: Facts are enemies of the truth.* Nikkei Publishing Inc., 2011.
5 *Newton*, January 2002. Newton Press.

■ Figure 6 Flow of Dr. Ryoji Noyori's research and the research funds provided



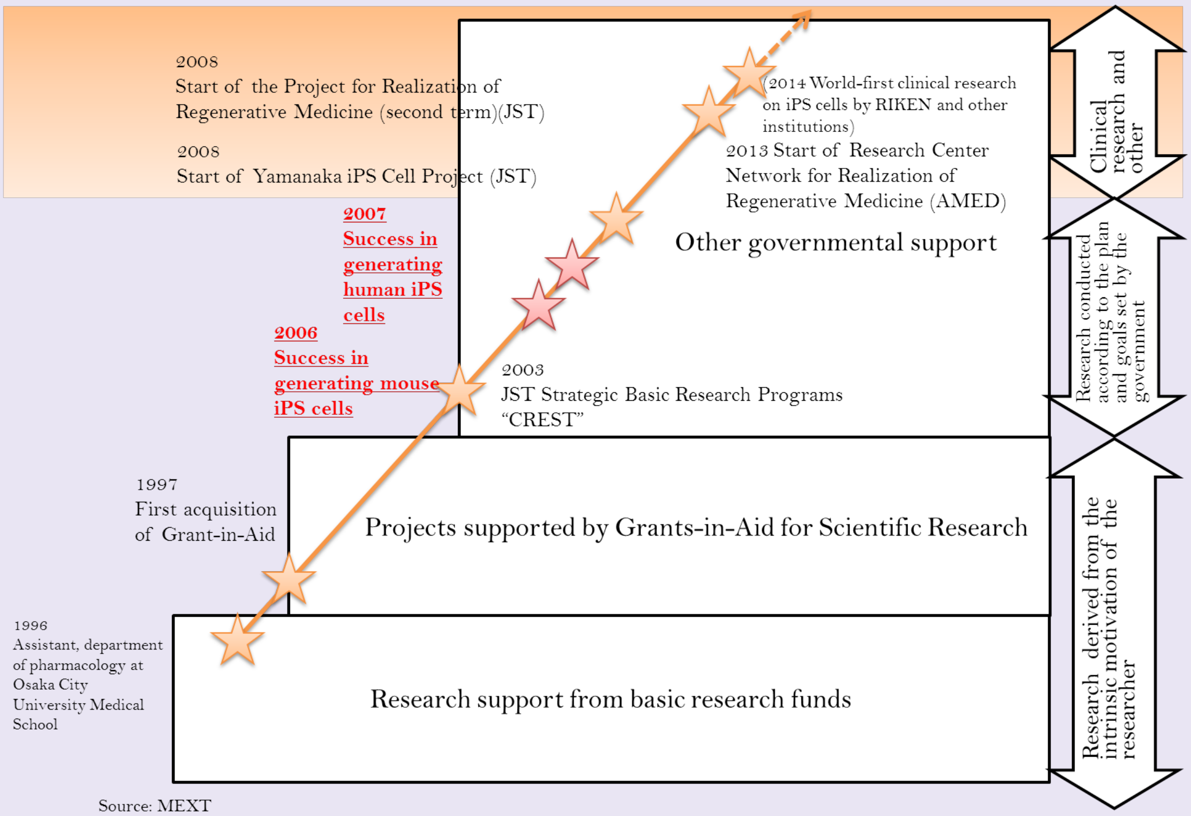
Source: MEXT

As for Dr. Yamanaka, the flow of his research leading up to the Nobel Prize is summarized in Figure 7. Dr. Yamanaka obtained his first grant-in-aid in 1997, and he continued to receive the support of grants-in-aid until 2012 when he was awarded the Nobel Prize. His research was accepted as a project under the Strategic Basic Research Programs CREST in 2003. Thus, he developed his research. These governmental supports resulted in successes in generating mouse iPS cells in 2006 and human iPS cells in 2007. A variety of support was provided after that, including that of the (second) Project for Realization of Regenerative Medicine, that of the Research Center Network for Realization of Regenerative Medicine, and that of the Funding Program for World-Leading Innovative R&D (FIRST).

When we look at the government assistance that was behind the success of iPS cells, continued support that had started well before the research achievements gained international attention is found to have played an important role. An example of such support is a grant-in-aid that will be provided to research programs whose uniqueness is appreciated. In addition to that support, the presence of a "connoisseur" is thought to be a key to success. In CREST, the decision of whether to fund a research program is the responsibility of the research supervisor. Therefore, the research supervisor's skill as a "connoisseur" makes it possible to discover researchers who will conduct promising research. Dr. Yamanaka was discovered by Professor Tadamitsu Kishimoto of Osaka University (currently professor emeritus at Osaka University), who was supervising CREST in 2003. This is as good an example of "connoisseur" ability as that displayed by Akio Ishida, then senior principal examiner of the Research Project Promotion Division of the JST, who discovered Dr. Isamu Akasaki, who produced the research achievement of blue LEDs.

At present, Dr. Yamanaka is the director of the Center for iPS Cell Research and Application (CiRA) at Kyoto University. CiRA has introduced open laboratories, which indicates the importance of improving research environments such that cross-disciplinary exchanges are possible.

■ Figure 7 Flow of Dr. Shinya Yamanaka's research, and the research funds provided



Source: MEXT

Furthermore, in promoting large-scale academic research, basic research funds, such as those for developing facilities for large-scale projects and Management Expenses Grants from the government to national university corporations, have played a significant role. It can also be said that each research achievement was supported by a variety of governmental assistance, including research support by competitive research funds such as Grants-in-Aid, in addition to basic research funds.

One example is the detection of neutrinos caused by a supernova explosion, which led to Dr. Koshiba's winning of the Nobel Prize. The opportunity to observe neutrinos was not missed, thanks to funds for the development of facilities to promote large-scale projects for academic research. The funds enabled the systematic maintenance and improvement of observation equipment. Special expenses and other funds were provided for the operating costs of continuous observation. In addition, the remodeling of the Kamikokande detector, conducted jointly by Dr. Koshiba and Dr. Yoji Tozuka with grants-in-aid provided from 1986, contributed to the detection of neutrinos. With the Super-Kamiokande detector, the successor to the Kamiokande, Dr. Kajita produced research achievements that earned him the Nobel Prize. Continuous observations using the Super-Kamiokande have been supported by basic research funds, such as facility improvement funds for the construction and maintenance of observation equipment, and government subsidies for maintenance and operating costs of the equipment. In addition to the above, support by grants-in-aid has been conducted.

To produce research achievements such as these, systematic improvements to facilities and equipment relating to large-scale projects of academic research are crucial. For example, the Kobayashi-Masukawa theory of CP violation, which brought Nobel Prizes to Dr. Kobayashi and Dr. Masukawa, was confirmed at the High-Energy Accelerator Research Organization using the KEKB B-Factory, an electron-positron collider. The Super-Kamiokande detector at the Institute for Cosmic Ray Research, University of Tokyo was used to discover neutrino oscillations, which revealed that neutrinos have mass. That research earned Dr. Kajita the Nobel Prize. These outcomes would not have been possible without the systematic development of facilities and equipment by the government.

On the one hand, large-scale projects such as this have been conducted in the face of fierce international competition. On the other hand, large-scale projects can be conducted through international collaborations, with each participating county assigned a role. International collaborations will enable the effective, efficient promotion of projects, taking advantage of Japan's strengths. They will also contribute to the improvement of Japan's research status in the world. In addition, equipment procurement through close collaboration with private companies is also important, as is seen in the case of Dr. Kajita and Hamamatsu Photonics K.K. described in 1(2)②(iii).

And human connections play an important role in research progress. In the case of Dr. Koshiba, his hoped-for participation in an experimental project in Germany was made possible by an unexpected invitation from a researcher he had known. In an interview in 2009,[1] he stated that it is human networks based on relationships of mutual trust that we should build. The remark suggests the importance of forging networks of researchers.

⑥ Conclusion

For the Japanese Nobel laureates in natural sciences who won the prize from 2000 onward, this section examined what led to their win by addressing several items. With the results, the following can be said as in (Figure 8).

1 Club Unisys+, vol.19. March 2009.

■ Figure 8 Summary of the life courses of Japanese Nobel laureates, and conclusions drawn from them

○ Many of Nobel laureates nurtured their interest in and admiration for science and technology as children through exposure to science and technology and the influence of Japanese Nobel laureates. **Fostering personnel who will lead the next generation is important** if Japan is to achieve sustainable improvements in prowess regarding Science and Technology innovation. In light of this, **it is crucial to increase the number of children who like science and mathematics** by providing education that fosters the creativity, capabilities and talents of children and by offering opportunities for children to study science and math.

○ Many of the Nobel laureates gained posts when they were young researchers, which allowed them to determinedly pursue their research without worrying about employment and to generate the achievements that led to their Nobel Prizes. Add to that, young researchers can start their careers by getting posts at national universities in outlying areas across Japan. This is Japan's advantage. It is imperative to make good use of it and to **improve the research environment for young researchers so that they can demonstrate their abilities and motivation to the full at each step of their career**.

○ Many of the Nobel laureates studied or researched abroad. Through friendly competition with the world's top-level researchers abroad, they gained diverse approaches to their research while building human networks. These greatly contributed to their being awarded Nobel Prizes. This means **it is of vital importance to strengthen international research networks**. It is also important for Japan to attract brilliant students and researchers from around the world and to play a role in nurturing future Nobel laureates.

○ Many of the Nobel laureates received assistance from the Japanese government, such as secured grants-in-aid and other research funds and the systematic maintenance and construction of research facilities and equipment. This shows that **various kinds of government assistance are indispensable** to the fostering of Nobel Prize-winning scientists. Furthermore, **it is important to promote innovation in science and technology by improving the research environment** in the following ways: joint research by industry-academia-government collaboration; cooperation between small- medium-sized businesses and venture businesses; enhancement of the "connoisseur" system in which research themes that have the potential for commercialization are singled out for governmental support; joint creation among researchers/ research institutions in different areas; and the construction of human networks.

Source: MEXT

The Nobel Prize is awarded to a researcher for the outstanding ideas and extraordinary efforts of the researcher himself or herself. Nevertheless, if Japan is to continue to produce Nobel laureates, the government needs to appropriately develop human resources. In elementary school and lower-secondary education, we should foster children, who are our future. In higher education, students' motivation and abilities should be cultivated.

In addition, to improve research environments such that they are ones in which young researchers with Nobel aspirations can perform at their best, it is imperative that the government carry out necessary efforts in a steady, integrated manner, such as by reforming personnel systems, providing research funds responsibly, and constructing systems for creating innovation using science and technology.

Column
Feature 5

Obtaining the right to name Element 113

"Element 113," discovered by a research group (the Morita group) headed by Dr. Kosuke Morita, group director of RIKEN and professor in the Graduate School of Science at Kyushu University, was verified as a new element by an international institution. As the discoverers, the Morita group was given the right to name the new element. No research group outside the West had never been given that right. The element discovered by the group in Japan is to be added to the periodic table of elements, a first for an Asian nation.

Deliberations on newly discovered elements are conducted by the IUPAC/IUPAP Joint Working Party, consisting of 5 members recommended by the International Union of Pure and Applied Chemistry (IUPAC) and the International Union of Pure and Applied Physics (IUPAP). Deliberations by the Joint Working Party confirmed the claims of the Morita group. The party concluded that the group fulfilled the criteria for the discovery of an element, noting that the three examples of decay chains observed in 2004, 2005, and 2012 were not mutually inconsistent and that the decay chains were associated with known atomic nuclei by "cross reactions" that generate the same atomic nucleus from the combinations of different atomic nuclei.

A joint research group consisting of an institution in Russia and an institution in the U.S. claimed to have discovered element 113 by using another method. As to that group's experiments in 2004 and 2007, the IUPAC/IUPAP Joint Working Party concluded that, at the time RIKEN fulfilled the criteria, the joint research group had not fulfilled it, because no decay chains had reached known atomic nuclei nor had any cross reactions been conducted.

Preliminary studies on the nucleosynthesis of super-heavy elements started at RIKEN in the late 1980's. Full-scale experiments on such nucleosynthesis using the "RI Beam Factory (RIBF)," a heavy ion accelerator, started in 2001 after the introduction, to the RIBF, of the Radio Isotope Linear Accelerator "RILAC," which has the highest beam intensity in the world, and the GAs-filled Recoil Ion Separator "GARIS." In September 2003, experiments started on the synthesis of a new element, element 113, in which a beam of zinc (Zn: atomic number 30, mass number 70) was fired at bismuth (Bi: atomic number 83, mass number 209). The nucleosynthesis of a new element (atomic number 113) was successfully performed in July 2004 for the first time. The results were successfully reproduced in April 2005 and August 2012. In addition to the reports of these three successful nucleosyntheses of element 113, the 2009 experiment, which directly synthesized bohrium (Bh: atomic number 107), provided important confirmation of the nucleosynthesis of element 113. Bohrium is the atomic nucleus that is generated when element 113 undergoes alpha decay four times.

Elements with atomic numbers greater than that of lawrencium (Lr: atomic number 103) are called "super-heavy elements." They do not exist in nature, because they are unstable and easily decay into other elements.The U.S.A., Russia and Germany have been fiercely competing to discover new super-heavy elements. To artificially synthesize super-heavy elements, you need to prepare a target atomic nucleus and cause reactions in that nucleus by hitting it with an accelerated nuclear beam using a particle accelerator. The amounts of super-heavy elements that can be generated are extremely low and their lives are very short. That is why it is difficult to prove the synthesis of new elements from analyses of chemical properties alone. For this reason, it is very important to confirm that the element has undergone decay chains and reached known atomic nuclei. The Morita group is the only research group in the world to have confirmed that the decay path of element 113 reached known atomic nuclei. That is the determining factor for recognition as the discoverer of a new element.

Discoveries of four elements, including element 113, were confirmed by the Joint Working Party in early 2016. (The IUPAC announced the discoveries of elements 115, 117, and 118 by research groups in the U.S.A. and Russia.)

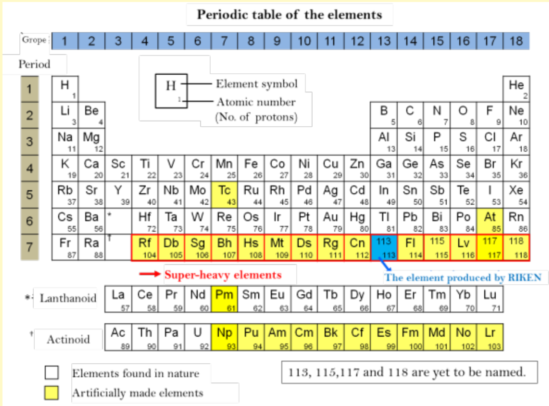
This has completed the 7th period of the periodic table of the elements. In the future, research will seek new elements with atomic numbers of 119 or over in the 8th period of the table and will seek a region called 'the island of stability', which is beyond the super-heavy elements. The lives of atomic nuclei are extremely long on that island.

The confirmation of element 113 was the first confirmation of a new element in Asia or in Japan. In research on elementary particles and atomic nuclei, fierce international competition has been continuing, such as the competition for the discovery of the Higgs boson. The confirmation has also shown the world Japan's prowess in science and technology. Accelerators and measurement apparatuses that were developed for the above purposes were designed by researchers at RIKEN and manufactured by Japanese companies. To improve Japan's prowess in science and technology, Japan is expected to continue its efforts toward developing accelerators and measurement apparatuses.

In addition, the confirmation of the new element brought broad public understanding in Japan that the achievement came from experiments carried out tirelessly over many years by the Morita group. The naming raised the need to revise the periodic table of the elements in textbooks for students of junior high school age or older, which is expected to promote an interest in science among Japanese.

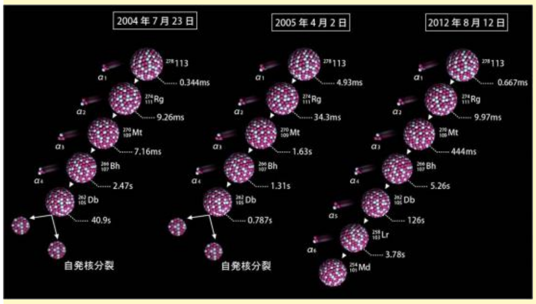
Press conference on Dec. 31, 2015
Kosuke Morita, Group Director of RIKEN (center), Hiroshi Matsumoto, President of RIKEN (left) and Hideto En'yo, Director, Nishina Center for Accelerator-Based Science (right)

Source: RIKEN



Periodic table of the elements (As of Jan. 2016)

Source: RIKEN



The decay routes seen in the three events

Source: RIKEN

RIKEN Heavy-ion Linac (RILAC)

Source: RIKEN

Gas-filled Recoil Ion. Separator (GARIS)

Source: RIKEN