The Development of Modern Sciences in Japan

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Intellectuals in Tokugawa Japan

Japan had a fairly limited *local* tradition of inquiry into the fundamentals of the natural world. Early intellectual traditions were strongly influenced by texts brought over from China.

In the Tokugawa feudal system (士農工商), there was no established place for intellectuals and professionals working in specialist fields (physicians, teachers, clerks, mathematicians, astronomers, and so on). Hence, there was no clearly defined social role for the researcher in Tokugawa, and those who did research or publish, did so individually. There was little or no institutional support for the production of knowledge for its own sake.

There were few norms for "professional" behavior among intellectuals.

- Scholars often kept secrets from colleagues, refused to publish, presented arguments in bits and pieces, and so on. Most careers were hereditary.

“Scientific” Careers

There were a number of different routes to a “scientific” career. Such as, hereditary routes:

- the official translators of Nagasaki, and later Edo,
- the physicians,
- the astronomers employed by the shogunate and some some daimyo for the regulation of the calendar,

and occasionally others:

- merchants, wealthy farmers, and samurai.

There was little class advancement, although very occasionally commoners could advance to the samurai class based on scientific achievements.

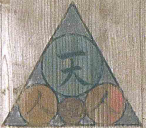
During the Tokugawa period, intellectuals were underpaid. A high ranking samurai might receive 8,000 *koku* 石, but no Confucian scholar ever received more than 3,500 *k*. The average for scholars in official positions was around 300 *k*. A physician could earn between 150–5,000 *k*.

Tokugawa Mathematics

Mathematics had little official place in society. Early on, there were some samurai mathematicians, but later mostly commoners. Nevertheless, there was a tradition of Japanese mathematics that was developed largely independently of Western mathematics (*wasan* 和算, *sangaku* 算額, etc.).

Wasan was associated with methods for solving equations, linear algebra and calculus-like methods. It was largely a local development based on an extension of mathematical techniques learned from the Chinese classics.

Sangaku were problem boards that were placed in temples and shrines. There was fairly little successfully applied mathematics and most people regarded advanced mathematics as useless. Indeed, many mathematicians thought that mathematics *should* be useless.

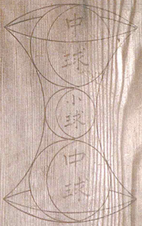


今有如圖三角內容天圓一箇
地圓一箇人圓二箇只云三角
面若干問得人圓徑術如何
答曰 如左術
術曰置四十八箇平方開之內減五箇
方開之加三箇以除三角面得人圓徑合問

今有如圖平圓內容甲圓二箇
乙圓三箇只云甲圓徑若干問
得乙圓徑術如何
答曰 如左術
術曰置二箇平方開之加二箇名極八之
減五箇餘平方開之內減極餘自乘之以除
甲圓徑得乙圓徑合問

正月

伊佐爾波神社



寄位置中球經內減小球經餘以除小球經爲九圓率

除五分爲冗矢依術求冗矢積以冗矢除之減

乘寄位得外積合問


甲
乙
丁
丁
今有如圖平圓内容甲
各曰丁圓徑
及丙圓徑絲實列極自乘内減甲圓
圓徑合問
山崎昌
伊佐爾波神社

Segregation and Distain of Mathematics

There was a sort of segregation of mathematics from the other areas of study. In early the Tokugawa, samurai dominated in mathematics and did little other science. In late Tokugawa, the situation was reversed. The samurai increasingly needed to earn a living and felt that mathematics was useless for this.

Nishimura Tosato (astronomer), 1761:

"Mathematics is a childish subject in which only people wishing to seek fame by constructing impracticable theories… will indulge."

Yamagawa Kenjiro (early Meiji) was unable to study mathematics at school because

"mathematics was despised by the samurai as something which only the merchants should study… The same situation existed in every other region."

The Influence of China

Until the modern period, the most important foreign influence on Japan was from China. The number of Japanese scholars who could read Chinese was much greater than those who could read any other foreign language.

In the late Heian and early Tokugawa periods, even Western books were transmitted through their Chinese "translations."

The main theme of natural inquiry before Meiji was the accommodation of Western ideas into a Neo-Confucian framework.

- It was often claimed that Western ideas had existed in ancient China, or Japan, but had been subsequently lost, and were now being reintroduced.
- When Western ideas were introduced they were transplanted into the intellectual framework of the *Book of Changes*.

The Philosophy of the *Book of Changes* 易經

The *Book of Changes* is a text that consists of a set of 64 oracular statements based on hexagrams of six broken or solid lines ($2^6 = 64$), arranged into sets of 3 lines. The interpretation of these hexagrams involves a sort of cosmology and philosophy.

Yin-yang 陰陽 were two primary states or actions in the world. They always come into being together, oppose one another, transform from one to another and are in balance. They have certain key associations – Yin: black, female, receptive, night, valleys, etc.; Yang: white, male, active, dominating, day, hills. During the Heian and Tokugawa periods, the office of the astronomers was within the *Onmyoryo* 陰陽寮.

The text also relied on the concept of *five phases* 五行 – wood, fire, earth, metal, water – which explained change; and *li ch'i* 理氣, based on the notions of pattern and form, and spirit or agency. The detailed interpretations of these principles changed over time, depending on the scholars who discussed them.

An Example from Meteorology

Mukai, 1656

"In the summer, *yin ch'i* enters the earth and *yang ch'i* comes out of the earth. Therefore, the surface is hot, and the earth and well water are cool. In the winter *yang ch'i* enters the earth and *ying ch'i* comes out of the earth. Therefore, the surface is cold, and the earth and well water are warm. The water in the sea and the rivers follows the same principle. Scholars of the Southern barbarians [Westerners] know nothing of the *Book of Changes* and are ignorant of the theory of *chi'ien* and *k'un* (hexagrams 1 and 2).

Giving up the ideas of *li ch'i*, *yin-yang*, and *five phases* to pursue other things is not practical learning. They do not know the right way… Since Westerners do not comprehend the significance of *li-ch'i* and *ying-yang* their theory of material is vulgar and unrefined."

A Japanese scholar conversing with a Chinese sage and a European philosopher

Shiba Kokan, 18th century

Rangaku 蘭学

European learning, and local scholarship about this, was known as "Dutch learning" because during Tokugawa all European texts came through the Dutch. After the country was closed (*sakoku* 鎖国), only around 20 Dutch men were allowed to stay and trade on the artificial island of Dejima in Nagasaki. The Tokugawa government had a bureaucracy of hundreds of people to deal with the Dutch, including 20-50 translators – all paid by the Dutch.

In the beginning of the policy, books that mentioned Christianity were banned and hence there was very little access to European sources. In 1720, Tokugawa Yoshimune relaxed the regulations. But this was apparently not announced at the time. Many of the *rangaku* texts were translations of Chinese translations; others were sensational but not very insightful. Nevertheless, there were a number of texts that impressed the Japanese public with European science.

Dejima in the bay of Nagasaki, with Dutch ships to the right

Sayings of the Dutch, 紅毛雑話, 1787

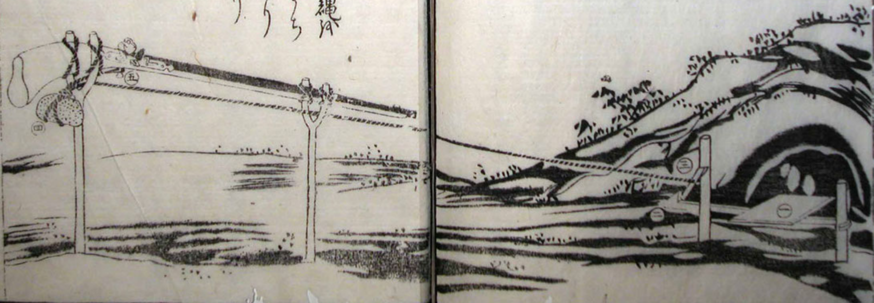
Kōmō zatsuwa: Exotic costumes from foreign lands

鉄鉋弶之圖

一 ふみ板へ足ふみかける
二 横木おちる
三 栓(せん)はづれる
四 錘(おもり)の石おちる
五 引金をひける

紅毛の鳥銃(てつぽう)ハ火縄なく
火燧(ひうち)にてうち
つるゆへ雨ふりにも
よろしきものなり

中良写



所なり。拂郎察にては「〓イレリイス」といふ。紅毛にては
「リユクトシキップ」船なり（「リユクトヒ」ハ氣、「シキップ」ハ又舟）「リユクトスロープ」（「スロープ」ハ小舟）といふ
「リユクトバル」といふ事あり（「バル」ハ球なり）「モレトコルヒイル」といふ人の工夫にて
「カルレスエンロベルト」といふ人創て製作せり。船の長サ一丈余、幅四尺余。
深サも同じ。人二人を載べし。船底は二重に作り。其内に
錻の鑑二ツを入おけり。此鑑移くの用方ありて〓櫓は煉鐵にて
張り長サ四丈余。兩の席を以て其櫓の蝶には球を附（球ハ革にて造る）[illegible]
[illegible]ありて此球の中に[illegible]
扨船中の人舵を動かし帆綱をおさへて上下縱横に
のまゝに飛行せり。若空中に風なき時は櫓へ帆はをさみつけ

リユクトスロープ之図

蠅

卵

一

折破んところ殻

二

かひそれてはおくの
わき虫とかめくも
白し

三

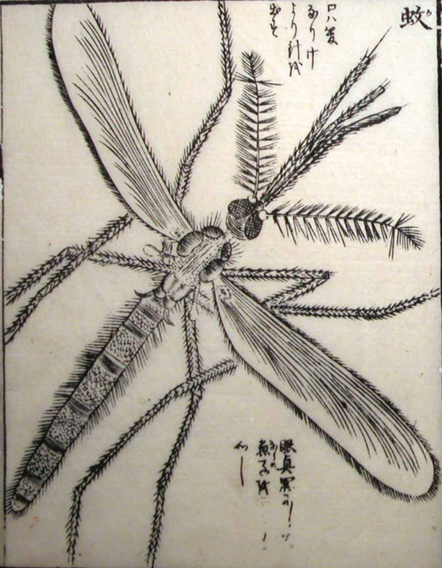
まゆのかくのやき形をして
あり日あらそ
蠅となる

四

五

蚊

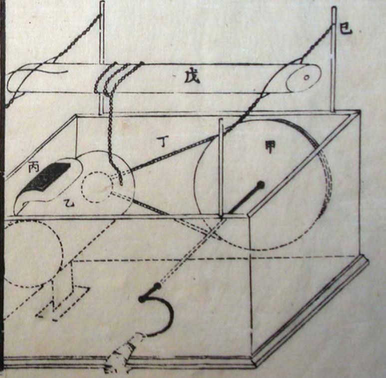
口ハ鍼
あり
より汁を
吸そ

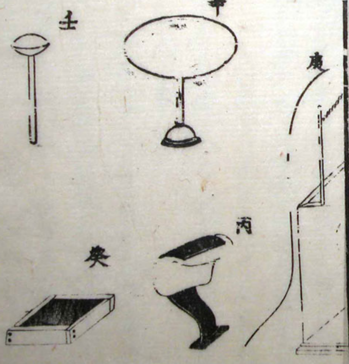


眼真黒なり
斑ある所
なし

紅毛雑話

同散啚






野禮義的爾之圖


政美画

Difficulties with *Rangaku*

- Holland was just one European country. In the 17th and 18th centuries they were scientifically, and economically, very successful, but Dutch was never a widely used European language.
- The Dutch at Dejima were merchants and had their own agendas for their interactions with Japanese scholars.
- Japanese scholars could not leave the islands, so it was difficult to develop language ability and to get access to original sources.

For these reasons, the interpretation that the *rangaku-sha* developed of Western science was often fairly local.

An Example from Newtonian Mechanics

Shizuki Tadao 志筑忠雄 (1760–1806), who had been trained as a translator, introduced Newtonianism through a study of two Dutch translations of Latin textbooks by John Keill (1671–1721): *Introductio ad veram Physicam* (1701), and *Introductio ad veram Astronmiam* (1718). This resulted in the *New Treatise on Calendrical Phenomena* (*Rekishō shinsho*, 暦象新書) (1798–1802).

Book I: Heliocentric theory. Astronomical tables for predicting local position. Kepler's laws. A discussion of the relatively of motion.

Book II: Neo-Confucian justification of Newton's laws. Discussion of gravity. Origin of the solar system.

Book III: Centripetal force. Properties of ellipses.

Confucian Metaphysics

After introducing Newton's laws of motion:

Shizuki, *New Treatise on Calendrical Phenomena*:

"The expansion of force always implies the contraction of the material. The contraction of the material always implies the expansion of force. Because of expansion and contraction, change is everlasting. Since force is monistic, everything is one. We dare not discuss the underlying principle concerning the cause of movement. If you want to understand the subtle principle of movement and density, you should study the *Book of Changes*."

Shizuki, discussion of mass:

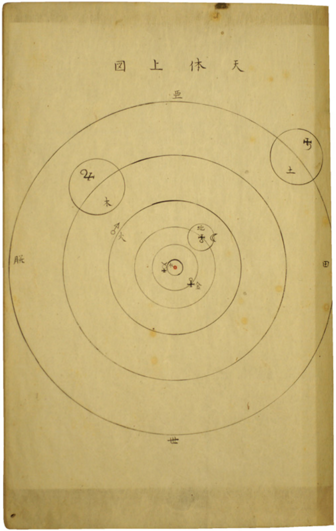
"The cause of all is change and flux and the one *ki* 氣. However, gravity is in objects of substance. Therefore, although it appears in myriad forms, there is an aspect of *substantive ki* 実氣 that is always comparable to gravity."

Heliocentric Theory

There is a potential problem with the heliocentric theory.

Shizuki, *New Treatise*…:

“Heaven is *yang* and earth is *yin*. Movement is the attribute of *yang* and non-movement is the attribute of *yin*. If the earth moves, it goes against the attributes of *yin-yang*. However, when I examine the idea of the Westerners over and over, it is hard to say that Western theory is not solid in its view of the mathematical principles of movement.”



Reconciliation

Shizuki, *New Treatise on Calendrical Phenomena*:

"I have the following idea: the main objective of the *Book of Changes* is to praise the wonder and function of heaven and earth. When it discusses the force of heaven, or heaven-as-agency and earth-as-material, heaven is *yang* and earth is *yin*. However, when it refers to the material of heaven and earth, it undoubtedly treats heaven as soft and light *yin*, and earth as tough and solid *yang*. It is like the hexagram *shih ho* in the *Book of Changes*. It reads, "There is something between the corners of the mouth." Mouth and the thing are earth. The space inside the mouth are heaven. *Yang* lines represent the mouth and the things, whereas *yin* lines represent the space. Hence, from this explanation, we come to know clearly that the material of heaven is *yin* and the material of the earth moves around the heaven."

Development of Modern Science, 1868–1918

Around 13 new institutes for scientific research were founded, all dedicated to development and testing. Around 90 Foreign science professors and teachers came to Japan, along with 200+ foreign technical experts. The government gave grants for Japanese scholars to study abroad. There was a gradual decline of traditional science and mathematics.

- **1893:** The Civil Servant Appointment Law (文官任用令)
- **1894–5:** Sino-Japanese War
- **1904–5** Russo-Japanese War

There was a shift to Japanese language and teachers in science education. Japanese scholars started to make scientific contributions within the modern framework – for example Nagaoka's "Saturn-like" atomic model.

- **1917:** Institute of Physical and Chemical Research (Riken, 理化学研究所)
- **1918:** New Universities Law

Importing Knowledge and Institutions

The policy of *Rich country, strong army* (富国強兵), was implemented by developing industry and military along "Western" lines. "Western" science was usually still perceived *as foreign*. The idea was to import knowledge and technique independently of philosophy and social conditions, so that it would be situated in the context of Neo-Confucian ethics.

In the early Meiji period, Tokyo Imperial University was the only place one could study scientific research. In the beginning, it was meant to be a state censor, to train bureaucrats, Confucian scholars and scientists – these different groups did not cooperate. During the Sino-Japanese War (1894–5), Kyoto Imperial University was founded. During the Russo-Japanese War (1904–5), Tohoku Imperial University was founded. Gradually, more imperial universities were founded.

Academic Nepotism

Scientists and journalists in the Meiji period often complained of academic nepotism, or “inbreeding.” In fact, the data shows that the only strong example of this was institutions hiring their own graduates.

- Hiring professors with family connections: little evidence for this.
- Hiring professors with other connections: evidence for around 20%.
- Hiring one’s own graduates: the evidence is that this was very prevalent.

Preferential Hiring in Japanese Universities

TABLE 6.3

Preferential Hiring in the Imperial Universities (1877–1920)[a]

UNIVERSITY \ FIELD	MEDICINE A	MEDICINE B	AGRICULTURE FORESTRY VETERINARY MEDICINE A	AGRICULTURE FORESTRY VETERINARY MEDICINE B	SCIENCE A	SCIENCE B	ENGINEERING A	ENGINEERING B
		N = 72		N = 44		N = 70		N = 89
Tokyo	62	90	52	82	72	90	89	94
		N = 72		N = 2		N = 24		N = 39
Kyoto	21	35	0	0	5	25	4	15
		N = 40		N = 4		N = 5		N = 33
Kyushu	2	13	0	0	0	0	0	0
		N = 25		N = 25		N = 27		N = 6
Tōhoku	0	0	26	76	6	19	2	17
Total N, A Columns	N = 622		N = 161		N = 177		N = 365	

Sources: *Dai jimmei jiten*, 10 vols. (1957). *Dai Nihon hakushi roku*, 5 vols. (1921–30). *Jinji kōshin roku*, 1st ed. (1903), 2d ed. (1908); 4th ed. (1915); 7th ed. (1925); 8th ed. (1928); 9th ed. (1931); 11th ed. (1937). *Who's Who in Japan*, 2d ed. (1913); 17th ed. (1936). *The Japan Biographical Encyclopedia and Who's Who*, 1st ed. (1958).

[a]Figures exclude Hokkaido University.

A: the percentage of PhDs 博士 from the university

B: the percentage of PhDs from that university held by its own professors

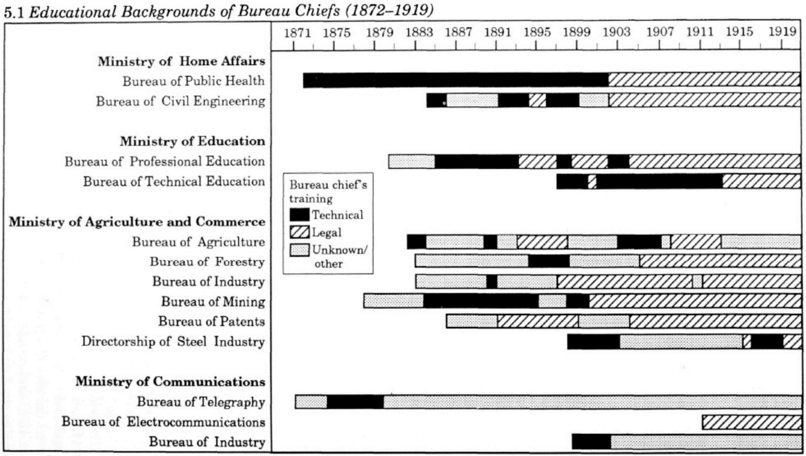
Administration and Funding

The main goal of the Meiji rulers was to create a strong centralized government, which would control all aspects of the country's development.

The administrators often had different ideas about the role and purpose of science than the scientists themselves. This was exasperated by the fact that administration of technical ministries was increasingly carried out by non-experts.

In particular, there were debates about the importance of basic research. With the blockades of Germany during WWI, the government finally came to realize the importance of basic science, because the country suffered shortages of basic chemicals, pharmaceuticals, dyes, and optical glass.

The Bureau Chiefs of Technical Ministries



Source: Ijiri Tsunekichi, ed., ***Rekidai kenkan roku*** (Tokyo: Hara Shobō, 1967).

The Civil Servant Appointment Law 文官任用令 was passed in 1893

John Milne (1850–1913)

Milne was born to a middle class family in Liverpool, England, educated at King's College, London, and the Royal School of Mines. He did field work carrying out geological surveys in Newfoundland, Labrador and the Arabian peninsula before he was hired by the Meiji government at the Imperial College of Engineering (1875–1895).

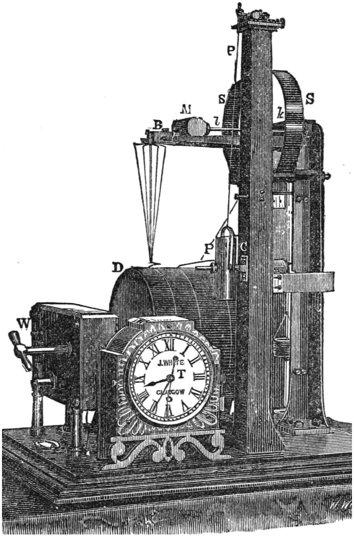
While he was in Japan, he and his colleagues essentially founded the science of seismology, and made Japan into one of the world's centers for seismological research. Milne was a co-founder of the Seismological Society of Japan and a co-developer of seismographs that could detect different types of waves produced by earthquakes and determine their velocities.

Later he worked on the anthropology of the Japanese islands, particularly the Ainu and the ethnic origins of modern Japanese, before retiring to the Isle of Wight, England.

Seismology in Japan

Following a large earthquake in Yokohama, 1880, Milne and a number of others began working on earthquakes. Milne and his colleagues began with £25 funded by the British Association for the Advancement of Science.

With a Scottish physicist, Thomas Gray (1850–1908), Milne developed seismographs which made continuous readings on graph paper. By setting up seismographs all over the country, Japan became the most important center for earthquake research.



Yamagawa Kenjiro 山川健次郎 (1854–1931)

Yamagawa was born into a samurai family, and sent by the Meiji government to study physics at Yale University. He was the first Japanese professor of physics at Tokyo University. He was ennobled (男爵), and moved into administration and politics.

He worked to introduce modern physics to Japan and to train the next generation of Japanese physicists.

- He produced a dictionary of physics terminology in Japanese, English, French and German.

He carried out original research on cathode rays and x-rays. Although his work was not considered to be critical in terms of the internal development of the field of physics, he worked to expand Japan's university system and to found new institutions for scientific research, and, hence, had a deep effect on the development of science within Japan.

Overview of the Rise of Technocracy, 1918–1945

During this period, there was a concentration on basic research.

1932: Establishment of the Japan Society for the Promotion of Science (日本学術振興会). Funding of research groups and collaborative projects.

1935: Yukawa's meson theory.

Ultranationalism: All science and technology for military purposes.

Technocracy was as movement by the technical elite to secure power in the government. The Civil Servant Appointment Law (文官任用令), 1893, made it almost impossible for anyone who did not have a law degree to serve as head of a ministry. Hence, there was a growing conflict between law-bureaucrats and technology-bureaucrats.

Colonial Technocrats

Following the Manchuria Incident, 1931, many engineers and other scientist joined in the "war fever." Professional organizations of engineers began to advocate for the development of Manchuria (Manchukuo) by Japanese firms.

Editorial, *Kojin Club Journal*, 1931:

"Japan and China can create a heaven of truly mutual prosperity by having Japan provide China with 'organization' and 'technology' and China supply its 'resources.'"

In Manchuria, technocrats could secure the senior positions that were usually reserved for law-bureaucrats at home.

The engineers created the image of Manchuria as a blank slate, waiting for Japan to develop it. The Japanese media helped promote this image and encouraged 350,000 Japanese farmers to immigrate. In fact, however, there was already a large workforce in Manchuria.

Science and Technology for Empire

Following the incident on the Marco Polo Bridge, 1937, Japan declared war on China. The wartime economy favored the interests of the technocrats. The government set up a number of planning agencies to coordinate science and technology development, staffed and run by technocrats. They began to develop an ideology of *technological imperialism*, under the belief that technology should be progressive, synthetic, and local.

The technocrats argued that science has nothing to do with *truth*, *natural laws* or *objective existence*.

They claimed that any idealization of the scientific project was misguided. That science was produced by technology and that it was not possible to understand one without the other. Moreover, the aims of science must be subsumed under the *national good*.

Shinohara, "Theory of Science-Technology," 1940

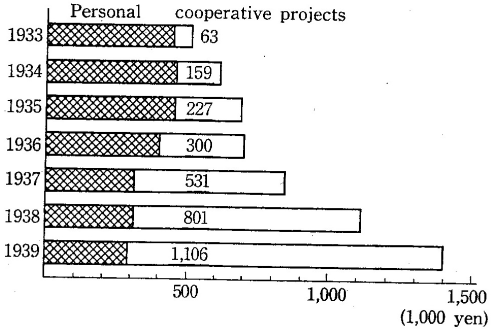
"Scientific research needs to be done in an organized and systematic fashion with a certain plan and control toward a clear objective for social production. Mere preference of individual psychology such as love of knowledge and admiration for truth needs to be absolutely excluded. It is imperative that scientific research be always conducted for practical purposes and that its results be materialized and industrialized immediately… Science is not simply a system of scientific laws; it needs to be interpreted as part of a wider activity that creates and applies such laws. Thus, the real issue in science is how to create the most efficient laws and how to apply such laws in a most efficient manner. This is precisely the issue in technology. Science is nothing but a system of technology in our intellectual activity."

The University Chair System

Before the Pacific War (WWII), Japanese universities functioned on a chair system, which had been based, in the 19th century, on the German university system – at the time the best university system in the world.

Each department, or school (学部, 学院), had a small number of chairs and each chair had control over the activities of those under him. Research grants were given directly to the chairs, who then made all decisions about how the money should be spent. Since, chairs did not work together, even generous funding of individual chairs did little to promote overall research productivity. Furthermore, there was no mechanism by which the government could directly influence research spending.

In 1932, the Japan Society for the Promotion of Science was founded to administer grants from the government and private endowments. It coordinated large scale research projects with industrial and military goals, and established subcommittees of technical experts to oversee the allocation of funds. One of the goals was the development of funding for collaborative projects.

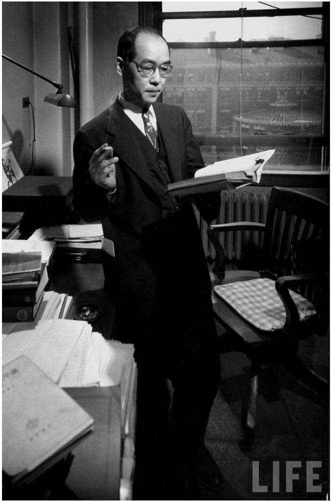


JSPS Subcommittees, 1933-40

Some examples:

- No. 1: Wireless instruments (¥206,345)
- No. 2: Economic exploitation of Manchuria, Mongolia and China (¥101,912)
- No. 3: Japanese encephalitis (¥111,211)
- No. 7: Airplane fuel (¥366,256)
- No. 10: Cosmic ray and atomic nucleus (¥326,927)
- No. 19: Special steel (¥135,945)
- No. 24: Metal casting (¥110,800)

Yukawa Hideki 湯川秀樹 (1907–1981)



- Born in Tokyo, educated at Kyoto Imperial University.
- Worked at Osaka and Kyoto Universities.
- 1935, published his theory of mesons.
- 1949, received the Nobel prize and became a professor at Columbia University.
- He headed the Institute for Theoretical Physics, Kyoto, 1953–70. (Now called the Yukawa Institute.)

New Particles and New Fields

There was some difficulty involved in applying the new theory of quantum mechanics to a phenomenon produced by cosmic-rays now known as beta-decay. Enrico Fermi had proposed a new particle, the *neutrino*, but it had not been observed. Yukawa combined Fermi's idea with Heisenberg's idea that a neutron can be converted into a proton by emitting an electron, e, and a electron neutrino, ν_e – and the contrary.

The mathematical model required new fields of short range forces, which, in turn, required a new particle some 200 times the mass of the electron. When Neils Bohr visited in 1937, Yukawa explained the theory to him, but Bohr was unimpressed. However, cloud chamber photos from the Institute of Physical and Chemical Research, Riken, in Tokyo, and elsewhere, soon showed the existence of such large particles – which became known as *mesons*.

Military Reaction

As in a number of European countries, the nationalists did not react well to the new science, especially as many of the scientists were moderate to left-wing in their politics.

For example, the editors of *World Culture* (世界文化), a left-wing magazine were arrested along with Taketani Mituo, one of Yukawa's collaborators.

Taketani was charged because he published his analyses of quantum mechanics, nuclear physics and his approach to the meson theory in *World Culture*. He was only released with the help of Yukawa, who's strong international reputation made him much less vulnerable to accusations by the nationalists.

Overview

During the Tokugawa period, there were a number of factors that made it difficult for the modern sciences to take root in Japanese society, such as little local support for science, cultural and linguistic barriers to foreign scientific works, limited social roles for intellectuals, difficulties developing technical and linguistic tools. Despite this, there was a growing interest in modern science and in the technologies that could be developed through it.

Although the Meiji period set the groundwork for scientific development, it was the two great wars that did most to direct energy and funds toward basic scientific research and change the institutional structure of science administration. Not all of this development was positive. As in other countries, the nationalists were often deeply suspicious of pure science and they harassed scientists to produce only the kind of technoscience that they wanted.