SHIGERU NAKAYAMA

CHARACTERISTICS OF SCIENTIFIC DEVELOPMENT IN JAPAN

1977

...NTRE FOR THE STUDY OF SCIENCE
...IOLOGY & DEVELOPMENT, CSIR
NEW DELHI

LECTURE SERIES 8/77

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Technology and Development,
CSIR, New Delhi

Printed at Aruna Printing Press, B-78, Phase II, Naraina Industrial Area,
New Delhi

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INTRODUCTION

We Indians tend to consider science in India as Eastern Science; the Japanese, however, consider Indian science as part of the Western tradition of science. Whatever may be the reasons, relative isolation of Sino-Japanese tradition or some exclusive features, such as heart being the centre of intellect, the Sino-Japanese tradition has some distinctive features which are worth studying. So far, the European developments in science and technology had been considered to be the main stream, whereas other streams were considered minor in character and incidental to the European tradition. Recent studies on the history of science in China and India and on the West Asian cultures have brought to surface considerable evidence to suggest the need for comparative studies in the development of science in order to know the significant features of science of a cultural area and its links with society.

Dr Nakayama, in these lectures delivered at the Centre, highlights some of the significant features of Japanese science. He, for instance, points out that science in Japan was imported from China, where its practical applications were more valued than the theoretical knowledge or basic theory. Further, in contrast to European tradition of science, where scientific research was directed towards philosophical and logical concepts to bring about understanding of regularities and on the basis of this to arrive at underlying laws, the Japanese tradition was inclined towards history and tended to look for discontinuities. In the words of Nakayama :

"These two tendencies were rivals in the formative period of philosophy in both Europe and the Far East. In the course of time, the emphasis became divergent in the two cultural spheres. The main current of the Western academic tradition remained centered upon philosophical and logical inquiries in the Platonic and Aristotelian traditions. Eastern scholarship definitely inclined to history with the Shih-Chi (*c.* 100 B.C.) of Ssuma Ch'ien as the prototype."

Further, he states :

"The absence of an anthropomorphic law-giver in their religion left the Chinese with little motivation to conceive laws of nature."

These remarks are rather pertinent for having a fresh look at the historical studies of science in India. The studies of history of science in India have so far been conceptually dominated by the European framework and the attempt has been to find similarities to what happened in Europe. It would be desirable to delink the studies with the Western framework and study science in India in terms of its own intellectual framework and the goals it has set for itself and then compare it with the other traditions of science in different cultural areas. When seen from this angle, the development of science in India may turn out to be very distinctive if not unique, with some similarities common to the Western tradition, others similar to those of China and Japan, while having some of its own distinctive features.

Dr Nakayama covers in his first three lectures the development of astronomy, medicine and mathematics in Japan and the characteristic features of these branches of science and the links of these developments with society of the period.

In the last lecture, he discusses the role of science and technology in modern development. In this lecture, he discusses at some length Western influences, the impact of Western science and technology on education and society, and as a result the new emphasis of different fields of science, the government's efforts in directing science and technology. In dealing with these, Dr Nakayama brings to surface some of the characteristics of Japanese cultural factors and their impact on the organization of science and technology — like the Samurai spirit and its impact on science and technology, problem of language, the dual structure of science and technology, the rise of technocrats in society and decisive role of industry in the direction of science.

The discussion of these factors would also be of considerable interest to the students of science in India, as a comparison of developments of science and technology in two Asian countries under the impact of Western cultures — in one, which came to be politically dominated and colonized and the other remaining free. This comparison may reveal not only the impact of colonization but the limitation on the growth and direction of science and technology as a result of the latter.

We are grateful to Dr Nakayama for making available to us the text of his lectures and thus enable us to reach a wider circle of those who, though interested, could not attend his lectures.

A. RAHMAN

ASTRONOMY

Pseudo-science and Science

Technical professions began in Japan with the immigration of Korean and Chinese experts in the sixth to eighth centuries. When the immigrants were slowly settling down, the Chinese view of nature which they carried along with them also, began to take root in Japan; it was later institutionalized on continental models in the College of Confucian Studies and the Board of Yin-yang (divination) art. The Yin-yang Board had three departments, observational astrology, calendar-making (mathematical astronomy) and Yin-yang divination. In principle it was a miniature reproduction of the Astronomical Bureau in the Chinese court. A closer look discloses significant remodelling to meet local requirements. In China, the Divination Bureau was administratively separated from, and much inferior in status to, the organizations that computed the ephemerides and observed celestial phenomena for astrological purposes. In Japan, all of these activities were subsumed under the single Yin-yang Board, the name of which indicates a clear priority for divination.[1]

The Japanese Yin-yang art was a complex of magical divination techniques. These techniques had little in common with the portent astrology practised in the Chinese and Japanese courts, which was based on a belief that the natural and political orders influenced each other in such a way that changes in the former could be taken as warnings about inadequacies in the latter. Throughout the sphere of Chinese culture calendar-making was the paradigmatic exact science, used for computing solar, lunar, and planetary positions, forecasting eclipses, and composing a complete luni-solar ephemerides.[2]

Although both the Yin-yang art and portent astrology were ways of forecasting changes in human affairs, the latter depended upon unpredictable omens, such as comets and irregular eclipses, as indexes of mundane crises. The Yin-yang art, because it was less passive, was more important in the everyday life of the court—determining the dates of court ceremonies, fixing propitious directions in which to begin journeys, and so on.

Much of this divination (in particular, the kind called hemerology) was based on cyclic notations of the year, month and day, and therefore was an outgrowth of calendar-making. In general, the goals of mathematical astronomy were universal; local differences in the motions of the sun and moon were trivial. Given a Chinese manual from which to determine basic parameters and computational procedures, there was little that local talent or preference could add, at least to the routine work of making the yearly ephemerides. On the other hand, when unforeseen and ominous celestial phenomena were seen, they had to be interpreted without delay. No Chinese book could cover every contingency, and there was no time to consult with the astrologers of the Chinese court. In astrology the Japanese were thrown upon their own resources. In Japan as elsewhere, the practical applications of imported knowledge were valued over basic theory.

Theoretical elements from Chinese natural philosophy played an important part in the interpretations of the Yin-yang art and of astrology. There was an old belief, for instance, that the northeast (*Kimon*, the gate of the demon) was a channel of unlucky influences. The Yin-yang art explained it as "the direction from which the god of Yang enters and the ch'i (energy) of Yin goes out". But this notion did not imply a strictly deterministic causal principle. It was merely a warning so that counter-measures might be devised; otherwise the art would have no practical use. For instance, people avoided building houses at places where the configuration of the land opened toward the northeast. Nor was astrology thoroughly deterministic. Before a predicted solar eclipse appeared to cast doubt upon the emperor's virtue, he could defend himself by calling in Tantric Buddhist monks to exorcise it.

Although astrology and alchemy are often called pseudo-sciences, they are neither misconceived sciences nor forerunners of modern science. Their goals are in no sense those of science. Science may be defined as a pursuit of regularities which underlie natural processes. Astrology assumes that the future may be predicted and that defensive measures may avert undesirable futures; alchemy of the Chinese kind assumes that eternal life is possible. It is true that they assume certain regularities in nature, but these are means rather than goals.

Although the astronomers who computed the calendar were thought of as mere functionaries, the master of astrology and the practitioner of alchemy were regarded by laymen as men of more than ordinary wisdom. As in early Europe, therefore, astrology was the higher art. Only in the Tokugawa period (1603-1867) when Confucian rationalism became intellectually predominant, could the official astronomers of the

Shogunate (the military government) attain high status by monopolizing the scientific aspects of calendar reform. Even so, traditional prerogatives kept them formally subordinate to the Abe family, hereditary masters of the Yin-yang art.

Western Orientation Toward Regularity versus Japanese Orientation Toward the Extraordinary

As we had just seen, it was not the regularities of eternal truths of mathematical astronomy but the unforeseeable omens of the astrologers that attracted attention in Japan. Only after Western influence did academic disciplines (*gakumon*, Chinese *hsueh-wen*) come to be considered predominantly as parts of a converging search for eternal laws and for enduring realities.

We may juxtapose these two tendencies as orientation toward regularity and orientation toward the extraordinary. Exaggerating the difference for heuristic reasons, we may say that the former assumes that there are eternal and universal truths, and seeks to formulate underlying laws. The latter denies that such truth is attainable, and is therefore not disposed to debate its existence. Those who relentlessly pursue regularity overlook the individual and the accidental. Those who value the extraordinary, pay little attention to persons or events that conform without deviation to stereotyped patterns. If the former are unresponsive to change because of their preoccupation with order and system, the latter reject change reflexively because they lack set principles against which to measure it. Philosophy, especially natural philosophy, strives toward underlying laws, while historians, including students of natural history, are attracted to discontinuities.

These two tendencies were rivals in the formative period of philosophy in both Europe and the Far East. In the course of time the emphasis became divergent in the two cultural spheres. The main current of the Western academic tradition remained centered upon philosophical and logical inquiries in the Platonic and Aristotelian traditions. Eastern scholarship definitely inclined to history, with the *Shih-chi* (*c.* 100 B.C.) of Ssu-ma Ch'ien as the prototype.[3]

Various conjectures have attempted to explain this bifurcation. Joseph Needham argues that the absence of an anthropomorphic law-giver in their religion left the Chinese with little motivation to conceive laws of nature.[4] As intellectual centres shifted in the West, there was only one centre of activity in China, and historical records accumulated in a single language. The early appearance of a true bureaucracy encouraged the development of chronology and the systematic compilation and classification of administrative precedents. The early availability of paper and the currency of printing by the year 1000 made historical literature more subject to ideological control, and thus more central to political and social concerns.[5]

Historical analogy rather than tightly constructed chains of logical reasoning became predominant in Eastern learning. This was even true in natural science, so that even though there were considerable overlaps of subject matter in East and West, there were enormous differences of style. Abstraction and involved theoretical argument were by no means rare in Chinese science, but, as I have already noted, were vastly less important in Japan.

It is well known that in ancient China historical scholarship grew out of the recordings of astrological portents to provide an empirical foundation for future prognostications. From the time of Ssu-ma Ch'ien, whose duties included astrology and history, such omens were an important component of the imperial chronicles. The positivistic view of history predicts that the horror of celestial omens, such as eclipses, should evaporate with the development of rationality. This was not the case in China, because such foreboding was a social rather than a psychological phenomenon. The astrologer-historians were also mathematical astronomers, and strove to remove phenomena from the realm of the ominous by making them predictable. Once that happend, such events lost their significance in astrology. What could be predicted no longer had news value, and no longer need be individually recorded in the annals.

The Platonic conviction that eternal patterns underly the flux of nature is so central to the Western tradition that it might seem no science is possible without it. Nevertheless, although Chinese science assumed that regularities were there for the finding, they believed that the ultimate texture of reality was too subtle to be fully measured or comprehended by empirical investigation. Japanese paid even less attention to the general while showing an even keener curiosity about the particular and the evanescent. In keeping with the orientation toward regularity in the early West, phenomena that could not be explained by contemporary theory, such as comets and novae, were classified as anomalous and given scant attention. In the history-oriented East, extraordinary phenomena were keenly observed and carefully recorded. The incomparable mass of carefully dated astrological records has proved invaluable to astronomers of today.

One might say that in the classical Western tradition there is an urge to fit every phenomenon into a single box; those unassimilable to the pattern thus formed were rejected. In the Eastern tradition, in addition to the box in which all the regular pieces were assembled, there were a great number of others in which irregularities could be classified. Sorting exceptional phenomena into the proper boxes was as satisfying for Japanese as fitting together the puzzle in his single box was for the Platonist (the Chinese preference was intermediate). If science is defined, as Europeans conventionally do, as the pursuit of natural regularities, the Far Eastern tradition is bound to appear weak because it lacked analytical rigour. Judged less ethnocentrically, there is some merit in its relatively catholic and unprejudiced interest in natural phenomena.[6]

When a court astronomer in Peking or Kyoto found that the position of the moon was radically different from what he computed, one would expect him to consider his theory to be compromised. Such crises often occurred in China, but there was an alternative that can be seen with some frequency there and quite often in Japan. The phenomenon could simply be labelled "irregular". It was not the astronomer's fault if the moon moved erratically.

This attitude may be seen in the career of Shibukawa Harumi (1639-1715), the first official astronomer to the Japanese Shogun, in a form more distinct than can be found among his Chinese contemporaries. In the preface to his early treatise, *Shunju jutsureki* (discussions on the calendar reflected in the *Spring and Autumn Annals,* the oldest Chinese chronicle), he stated "astronomers have rigidly maintained that when Confucius dated the events in his Annals of the Spring and Autumn era he made conventional use of the current calendar with little care for its astronomical meaning, so that the dates are not very reliable. This error is due to their commitment to mathematical astronomy, so that they do not admit that extraordinary events happened in the sky .....Extraordinary phenomena do in fact take place in the heavens. We should therefore not doubt the authenticity of (Confucius') sacred writing-brush".

In his own work on mathematical astronomy Shibukawa remained thoroughly positivistic, but he also left a somewhat problematic astrological treatise, *Tenmon keito* (Treasury of Astrology, 1698). Careful examination of these eight volumes of astrological formulas and interpretations of recorded portents disclosed that a large portion was inattentively copied from a famous Chinese handbook, Huang Ting's *T'ien-wen ta-ch'eng kuan-k'uei chi-yao* (Essentials of Astrology, 1653) (ref. 7). In this work he often expressed the skepticism toward astrological interpretations that one might expect of a practical astronomer. He often wrote "We do not know the basis (of this interpretation)......Is this unreliable?"

Shibukawa believed that a professional astronomer must be thoroughly competent in both major branches of celestial studies, portent astrology and calendrical science. His Jokyo calendrical reform (*c.* 1690) provided a box for regularities. It was no less important to furnish the means by which astrological portents might be classified. He was convinced that the heavens could not be fully comprehended through mathematical regularity. The sky was a unity of such depth that the tools of no single discipline could plumb it. Although he found astrological interpretations to be often equivocal, the vast historical accumulation of omen records suggested that it had to be taken seriously. There must have been, he thought, justified passion and reason behind that tireless activity of the ancients.

Once admitting, as Shibukawa did, that regular motion was too limited an assumption, one could easily conceive such notions as that astronomical parameters could vary from century to century. In the official Chinese calendar in the thirteenth century and earlier the discrepancy between ancient records and recent observations was explained by a secular variation in tropical year length.[8] Shibukawa revived this variation in the Japanese calendar, and Asada Goryu (1734-1799) extended it[9] to other basic parameters to account for Western as well as Eastern observations then available to him.

The variation terms used in Chinese and Japanese astronomy were too large to survive empirical testing, and were eventually discarded. Wherever the Aristotelian notion of an unalterable universe was followed rigorously, irregular motions in the sky were inconceivable. Even the mathematically justified variations in the precession of the equinoxes which had a brief career in Europe, entered it from Islam. After Newton, variations in parameters were acceptable to the extent that they could be given mechanical explanations. In the West, the first systematic study of variations in basic parameters was delayed until the time of Simon Laplace in the late eighteenth century. It is significant for the history of ideas that in China and Japan there was no reason to resist such variations.

In the Far East, not only were irregular motions of the celestial bodies admissible, but the algebraic approach to mathematical astronomy made it unnecessary to take a stand on the spatial relations of the sun, moon, and planets. The earliest astronomical schemes in China (first century B.C.) depended heavily upon a cyclic view of nature. These numerical models explained all of the calendrical phenomena by a vast construction of interlocking constant periods. The cycles of the sun and moon, the synodic periods of the planets and cycles of recurrence for such phenomena as eclipses were tied together by larger cycles determined by their least common multiples. By the end of the Han period, however, improved observational precision and recording accuracy made it clear that the heavenly courses were too complex to fit such simple assumptions. Eventually the metaphysical commitment to cyclical recurrence was abandoned.[10] Periods of recurrence became no more than algebraic constants to be used alongside a great variety of other numerical devices. Neither celestial morphology nor cosmic ontology were of further professional interest to astronomers.

The Chinese tradition of astronomy, including its offshoots in Japan, Korea, and Viet Nam, thus did not depend for its direction of development upon a dialectical relation between metaphysics and observation. Computational schemes neither challenged nor strengthened philosophers' conceptions of cosmic design.

The Difference Between Chinese and Japanese Views of Science

Ogiu Sorai (1666-1728), the most influential of all Japanese Confucian philosophers, had some interest in astronomy. He commented on the variation of astronomical parameters (Gakusoku furoku) : "Sky and earth, sun and moon are living bodies. According to the Chinese calendrical technique, the length of the tropical year was greater in the past and will decrease in the future. As for me, I cannot comprehend events a million years ahead." Since the heavens are imbued with vital force, the length of the year can change freely and constancy is not to be expected in the sky. Indeed, only a dead universe could be governed by law and regularity. The study of such a world would be of no interest to the natural philosopher. Since it was precisely the vital aspects of nature that interested Ogiu, he remained an agnostic in physical cosmology.

Indifference toward the search for regularities in nature prevailed in the School of Ancient Learning (*kogaku*), which emerged in the late seventeenth century with Ogiu as its leader. Its anarchistic and dynamic cosmology was bathed in historicism.

"All scholarship should finally converge in historical studies", said Sorai.[11] Because he was a Confucian philosopher, "history" meant humanistic history. Whenever the philosophers of the Ancient Learning School looked at nature, they saw it in the light of social and ethical concerns.

This moralistic, anthropocentric, and often anthropomorphic view of nature was common among Confucian thinkers all over the Far East. Many of them were unable to imagine that mathematical astronomy could make any greater contribution than to provide an accurate calendar.[12] Nevertheless, there were some notable differences between the views of Chinese and Japanese Confucians on the search for regularities in nature, especially with reference to calendrical science. Although these views were not imposed upon astronomers as corresponding ideas were in the West, the importance of philosophy in education makes them worth examining.

In China, computational astronomy was an integral part of the imperial bureaucracy. The head of the Astronomical Bureau, unlike his subordinates, was not a technical expert but a civil service generalist on his way up the career ladder. Many Confucian scholars wrote competently on astronomy, and books on the subject were often ornamented with prefaces and colophons by high officials.

In feudal Japan, occupations were hereditary. The post of official astronomer to the Shogun was created to recognize the personal achievement of Shibukawa Harumi, and was passed down to his descendants. It had no significance beyond the technical, and thus was of no interest to the generalist. Technical posts of this kind were from their origin separated from the general samurai bureaucracy. When the official astronomer and his subordinates were compiling the ephemerides, Confucian scholars were not consulted. Even the Tsuchimikado family, for many centuries astrologers to the imperial court in Kyoto, was not accorded the courtesy of an invitation to contribute a preface.

A popular Chinese book of negligible depth, the *T'ien-ching huo-wen* (Queries on the Astronomical Classics, 1675) by Yu I, exerted a considerable influence on Japanese cosmological notions. Among the many Japanese editions, the only preface by a Confucian scholar was that of Irei Shukei. Irei states in his preface that he was motivated to write a commentary on the simple work because most astronomical writings are so full of mathematics and technical terms that, although they may be "useful for the narrow calculations of small men engaged in the divinatory and computational arts, they are of no use for the greater mathematical concerns of gentlemen and scholars." It was no doubt commonly believed in China as well that calendrical astronomy, which Irei looked down upon, had lost its ideological implications and had become nothing but a collection of techniques. Still, Chinese, particularly from the mid-seventeenth century onwards, continued to think of astronomy as part of the Confucian system of learning. As Juan Yuan (1764-1849), a high official and patron of learning, put it, mathematics and astronomy are "a proper study for those scholars who search out the facts to get at the truth, and not a tool for technicians scraping up a living." In China, many Confucian scholars contributed prefaces to *T'ien-ching huo-wen* not merely for ornament but often to discuss fundamental technical matters.

What accounts for this difference ? Almost without exception, the computational schemes and theories used in East Asia were discovered by the Chinese. To the Chinese, they were integral parts of native culture; to the Japanese they were importations. In China, the lingering excitement of discovery clung to knowledge of regularities in nature. In Japan, these foreign regularities comprised one more routine skill prerequisite to established occupations.

This was true not only of science but of Confucianism itself. In China Confucianism was more than a philosophy; it was the basis of political legitimacy. The government's use of it as a political ideology demanded that great care be given to defining what orthodox Confucianism should be — just as the imperial monopoly of the calendar made it necessary to have one official system of astronomical computation. Official philosophy as well as official astronomy was exported to maintain China's cultural sovereignty among her satellites and neighbours. Confucian philosophy in its contemporary interpretations endorsed and justified these concerns. As is well known, the commitment of the Chinese elite to civil service channelled a great deal of intellectual energy in this direction. What interpretations should be orthodox, what sorts of learning should be propagated, were central subjects of philosophic inquiry. Not all thinkers shared the official view at any given time because it determined the content of the civil service examinations, about which much of early education was organized; and it was enormously influential.

In Japan, there was no social or political reason for philosophic orthodoxy to be an important issue. Although nominally based on the centralized Chinese model, Japanese government was, until a century ago, imposed upon a feudal society, and thus remained multifocal. Although dynastic legitimacy could not be taken from the imperial court in Kyoto, real political power lay entirely in the hands of the military dictator, the Shogun, in what is now Tokyo. He was able to keep that power only by leaving local authority in the fiefs (*han*). Certain prerogatives in astronomy belonged by tradition to the Tsuchimikado, the imperial court astrologers, and others were divided between the Shogunate astronomers and those of the fiefs. Satsuma, one of the larger fiefs, issued its own calendar. There was no occasion to establish a single orthodoxy, political or intellectual. Just as political and astronomical orthodoxy were related in China, their absence was related in Japan. This contrast is apparent even in the art of divination. The great Chinese treatise, *Wu-hsing ta-i* (Fundamental Principles of the Five Phases, *c.* 600), set out a coherent synthesis of contemporary knowledge and belief. The early Japanese treatise, *Hoki naiden* (Ritual Implement, undated), equally influential upon later practice, was an undigested juxtaposition of hemerological practices from Shinto, Buddhism, and perhaps Taoism as well. In Japan, freedom to choose between several paradigms seems to have been as desirable as the search for a unitary principle was in China. It might be added that when Japanese did originate something there was no expectation that it be universally accepted, that it have influence outside Japan. Although Chinese did occasionally acknowledge Japanese originality in connection with one development or another, Japanese before the twentieth century did not believe that they could contribute to universal systems of knowledge.

From the seventeenth century onwards, when Western knowledge began to exert claims of its own in the background of Chinese learning, Japanese thinkers were critically attentive. As soon as they were convinced that European technical knowledge was superior, Japanese switched to the new paradigm with remarkable promptitude. Japanese modified their attitudes smoothly and quickly toward desirable goals presented from abroad. For the Chinese, the encounter with European ideas was traumatic; to accept them was to reject traditional values, and to reject them would leave no defence against dismemberment by the Western powers.

MEDICINE

The Chest as the Seat of the Mind

Even as late as the middle of the nineteenth century, Japanese did not believe that thought takes place in the head. Even as late as in the mid-nineteenth century, an official astronomer wrote, "Mathematical principles all originate in the breast of the mathematical astronomer...... (Thoughts) are stored in the chest."[13] He was typical in situating both memory and arithmetical thinking in the chest.

To Japanese such terms as "a dull head" or "a clear head" have a modern and exotically occidental flavour; they were never used until the Tokugawa period. The cognitive imaginative functions of the brain were unknown, and their anatomical substrate undemonstrated, until the beginning of Westernization in Japan.

Traditional Chinese medicine, upon which the learned tradition of Japan depended, was concerned primarily with function and only secondarily with tissues and organs. The sites of function to which most attention was paid were two groups in the thorax, a set of six *fu* which ferment food, separate extracted energy from waste, and excrete the latter, and five *tsang* which store the refined energy. These spheres of function were identified with the familiar viscera, but the physiological nature of the latter was of such minor importance that little was known about it, and it played no abiding role in medical discourse. Occasional drawings of these viscera ignored both the interior of the head and the nervous tissues, neither of which were assigned specific functions (at least in the Chinese medical writing that was influential in Japan).

To my knowledge, the brain's function was first discussed in China in *Wu-li hsiao-chich* (Notes on the Principles of the Phenomena, printed 1664), by the idiosyncratic Fang I-chih, who was acquainted with the writings of the Jesuit missionaries. His knowledge originated in Western medicine.

In Japan thought was first located in the brain in an Amakusa edition, *Aesop's Fables*, which merely remarked "if we have intelligence in our heads..." Again it is clear that this idea was imported into Japan along with Catholicism. The notion did not spread until the study of the Dutch language (and consequently of secular sources) became widespread in the Japanese society, and in the early period there was not the slightest influence upon developing knowledge of anatomy, physiology, nor pathology.

It is well to remember that the inter-relation between the brain and the mental processes could not be proven before the development of cerebral psychology. The idea has a long history in Europe, but it is the history of a belief rather than of a fact.[14]

Plato and Aristotle held quite different views on the location of mental processes. Plato believed that the immortal and holy rational soul is located in the brain. Aristotle placed the centre of sensation and perception in the heart, and did not believe that it was related to the brain or spinal cord in any way.

These were not isolated opinions, but were integral with coherent views of the body and its functions. Plato and others who placed mental functions in the head had tended to think of them as quite separate from the physical body; schemata, which considered the heart and mind identical, had tended to think of mind and body as integral. Traditional Chinese and Japanese must be classed with the organismic and naturalistic group to which Aristotle belongs rather than with Plato's idealists. The experimental work of Galen settled the matter in the West, providing an authoritative basis for the doctrine that the brain is the centre of perception and of all other mental processes. The introduction of this idea into the Far East had implications at least as revolutionary as that of Copernican astronomy. It challenged the doctrine of bodily functions (and the rather negligible notions about internal organs related to them) and posed a range of questions about the physical basis of sensation that had not been previously considered.

Ogawa Teizo has located[15] the first Japanese appearance of terms that correspond to "nerve" and to consciousness as associated with the brain in the *Kaitai shinsho* (New Book of Anatomy, 1874) by Sugita Genpaku and others. Otsuki Gentaku, in his *Chotei kaitai shinsho* (New Book of Anatomy, revised), enthusiastically described the significance of the new study of the cerebral and nervous system in this way:

> "We have not come across anyone in the long Chinese and Japanese traditions who discussed the active functions of these organs of sentience. They were taken up superficially and in an elementary way only at the close of the Ming dynasty (early seventeenth century). Most regrettably, in the two hundred years since that time no one has taken up the problem in closer detail. It is a great pleasure

that now we are able to explore it more deeply. This is not particularly due to my personal endeavour, since we are all influenced by the trends of the times."

The learned treatises of the Chinese and Japanese medical traditions lacked terminology not only for brain function but also for mental process. Conventional Chinese discourse was not much concerned with what we would consider epistemology. Certain late Confucian schools were somewhat concerned with how knowledge becomes pure, but tended to connect this problem with that of attaining enlightenment. The vocabulary for mental operations remained rudimentary and was, to a considerable extent, borrowed from Indian Buddhism.

Although, as I have remarked above, the spheres of function within the body were thought to process nutriment and store the energy refined from it — and Japanese terms which predate Chinese influence such as *kusowatafukuro* and *yuharifukuro* are literally types of containers — knowledge was never thought of as localized and stored. There was no reason to investigate the physiological basis of cognition.

In short, the need to explore the relations between mind and brain did not exist in China because the Chinese assumed neither the mind-matter dualism nor the dualism between the self and the outer world. They saw all of nature as united in a single pattern of function in which the patterns of function of individual things (*li*) participate. The dualistic terminology used today in Japan, except for a few terms borrowed from fundamentally religious Buddhist dualism, were mostly invented by Nishi Amane and others at the beginning of the Meiji period (1870's and 1880's).

Anatomy and Energetics

In the East, what appears to be a rudimentary association of physical functions with internal organs does not indicate a low state of medical theory. Although the Chinese lacked the sophistication of Galen's anatomy, attempts to study rigorously the Chinese language of function in its own terms, a very recent development, suggests an artfulness that is obscured by the imposition of modern viewpoints. From the historical point of view, the fundamental question is not whether, before modern times, the Chinese or the European tradition incorporated the greatest number of correct facts, but how their theoretical paradigms, and the views of nature on which they depended, differed.

In Western medicine, before modern times, the rivalry between solidists and humouralists is well known. The aim of the former was to locate the seat of a disorder in a solid part of the body, such as the stomach or the brain. The motivation to pursue anatomical research is obvious. The humouralists, on the other hand, thought of health primarily as a balance of the various humours which circulate in the body. Anatomy had a great deal less to contribute to their holistic diagnoses.

Traditional Chinese theories of bodily function and of pathology are closer to the humouralist tradition than to that of the solidists. Health was related to the balance of *ch'i*, which is the basis of material organization and function not only in the human body but throughout the physical universe.

Ch'i was not a ponderable fluid as the humours were. It originated very early as the word for air—not as inorganic gas but as an enveloping substance that maintains vital function. Its closest analogue in the West was the stoic pneuma. In medical theory its vital or energetic aspect — in a purely qualitative sense — became preponderant in discussions of etiology. It was not only inspired air, but was the energy refined from food that circulated throughout the body and was responsible for all vital functions. The concept of *ch'i* as a material pneuma was to some extent reconciled with this energetic approach and was never abandoned; for instance, certain tumors and internal swellings were thought to be stagnated or congealed *ch'i*. Indeed, the seventeenth century Japanese physician, Goto Gonzan, attempted to explain the cause of all medical disorder by stagnation of this kind. As *ch'i* was involved in processes in physical nature or in the body, it took on different qualities or characteristics in different phases of such processes. If the whole process was analyzed into two phases, the two different types of *ch'i* were characterized as *yin* and *yang*; if a fivefold analysis was used, the five types of *ch'i* were described by the language of the Five Phases theory. A dynamic balance between the two and five successive types of *ch'i* defined health, ethical disorders were always identified with an imbalance.

The language of *yin-yang* and Five Phases theory was used to set up sets of correspondences that governed bodily function. For instance, the Five Phases corresponded to the five spheres of function (loosely identified with the heart, lungs, spleen, liver, and kidneys). But discourse about health and pathology was never anatomical. The system, identified with the spleen, amounted to the ensemble of functions that would be ascribed today to the urino-genital system, and was thought of quite functionally.

Internal disorders were never local in Chinese medicine. Although they might be concentrated in a particular sphere of function, the connection of the spheres by the energetic circulation system meant that the whole body was affected and that as the pathological process developed its seat would move. There was no point in local treatment. The site of treatment was often far removed from the momentary centre of concentration of the disorder. Abstract correspondences were often called upon in discussions of pathology and therapy — for instance, Five Phases correspondences between the heart and the ears and between the liver and the eyes. There were not so much statements about physical connections (although such connections were claimed to make the model plausible pneumatically), but about similarities and analogies of functions.

Early Far Eastern anatomical charts were extremely simple and crude. As Lu Gwei-djen and Joseph Needham have remarked,[16] they incorporate a much more rudimentary level of knowledge than the texts that they accompany. Why were Chinese physicians satisfied with them? Their purpose was obviously different from that of Western anatomical diagrams. They were simply meant to depict the broad outlines of the general system of physical function. One might think of them as half anatomical diagram and half flow chart.

According to this view of the theoretical entities of Chinese medicine, reconstructed largely through the painstaking work of Manfred Porkert,[17] it is possible to conclude that it was closer to the European humouralist point of view, although pneumatic in a sense that does not fit the European theory. It had no use for exact anatomy. For the latter to be accepted in the Far East, its utility would have to be proved, and it could only be proved by an appeal to a different conception of nature and of the human body.

Anatomy in Japan

When anatomical inquiry began in mid-eighteenth century Japan, did its demand for an analytical approach to the human body have revolutionary consequences?

Before the serious study of anatomy began in Japan, criticism of traditional Chinese anatomical charts on the basis of his own anatomical findings (1759) entitles Yamawaki Toyo to the title of forerunner of anatomical studies. Yamawaki's interest in anatomy must have been stimulated by access to a Western anatomical chart. Although he could not read the legends, his experience must have convinced him that the Western schema was a great deal more accurate than the Chinese. What led him to evaluate both as anatomical rather than as functional?

First of all, when Western knowledge began filtering into Japan during the Tokugawa period, it was naturally compared with the official

Chinese academic knowledge, since the latter had become firmly entrenched not very long before. It was natural to ask which set of ideas was better — unlike the case in China, where traditional ideas were so strongly rooted that such a question could only be radical. In mathematical astronomy, criteria of predicted accuracy were so obvious that Western superiority was quickly recognized. This was equally true in China, since the criteria for that recognition could be traditional ones. In medicine, there is good reason to doubt that there was any difference in therapeutic efficacy before the late nineteenth century. It is above all in the comparison of anatomic charts that the strength of Western medicine would be apparent. As I have argued above, however, the difference between Chinese and European ideas about the interior of the body would be *anatomically* significant only after the idea of anatomy, and the more general medical and philosophic ideas on which it was based, were accepted.

Yamawaki Toyo was, in fact, one of the leaders of a new group called the *Koihō* (Back-to-ancient-medical school), who rejected the theoretical entities of Chinese medicine and undertook an empirical approach to clinical treatment. Their utilitarian goals made the very elaborate conceptual superstructure of the Chinese tradition seem an impediment. Because they wished to confront as directly as possible the ills of the body, its role as a microcosm of physical nature could be rejected. As Yoshimasu Todo (1701-1773), the foremost figure of this school, declared, "*yin* and *yang* are the *ch'i* of the universe, and thus have nothing to do with medicine."[18] This group was prepared, then, to take a position much closer to that of the solidists than had been possible in Japan at an earlier time. Functional analysis lost its importance, and the physical organs could be studied for their own sake. From this point of view the traditional anatomic charts were recognized to be crude and inaccurate representations of material organs. This was nothing less than a gestalt change.

Still this conceptual radicalism was circumscribed. Yamawaki's accomplishment was not to do away with the old scheme of six processing spheres and five storage spheres but rather to alter them so that they made sense in anatomical terms. He had no reason to be curious about the contents of the skull. It was only later figures with considerable knowledge of Western anatomy, such as Sugita Genpaku, who could abandon the Chinese tradition entirely and display as much anatomical interest in the brain as in the viscera. At that point the confrontation between champions of the two systems becomes interesting.

Lately, there has been a tendency to emphasize the value of organismic and synthetic thought, such as Joseph Needham had found predominant in Chinese science, to the detriment of the early modern habits of physical reductionism and remorseless analysis. Although the pneumatic *ch'i* doctrine, and the *yin-yang* and Five Phases theories which qualified it, are not precisely reductionist, they are not of modern type either. All of these concepts, although originally abstracted from everyday phenomena, were too abstract to have fixed empirical significances. They remained satisfactory only because, as N. Sivin has shown (see "Shen Kua"[19]), the goal of Chinese science was not complete understanding of the natural world but only limited knowledge for practical purposes. The body was clearly not the cosmos, but the correspondence between the two set limits upon what could be asserted about the body.

Because of the special character of Chinese medical thought as received in Japan, we have examined in some detail the reasons that traditional doctors would find anatomy, and thus dissection, irrelevant to the improvement of medical therapy. There were other objections to dissection. The idea was deeply ingrained in Confucian ethics that the obligation to keep intact the body one had received from one's parents was a major tenet of filial piety. This prohibition against mutilating the body practically ruled out dissection in China. In Japan it had practically no effect on medical specialists.

A second objection to dissection originated in traditional physiology. Sano Antei in his "Hi zoshi"[20] (A Refutation of the Anatomical Charts, 1760) said "what the *tsang* (the word for the spheres of function and their associated viscera) truly signify is not a matter of morphology; they are containers in which vital energy with various functions is stored. Lacking that energy, the *tsang* become no more than emptied containers." In other words, what characterizes the internal organs is not their morphology but the differences in their functions defined by the energy they store. Nothing can be learned by dissecting a cadaver, since it lacks this vital energy. The anatomical charts that captured the imagination of Yamawaki, since they were based on dissection, could cast no light on the dynamic functions of the body. We can see the same point in another criticism Sano made. He noted that Yamawaki's anatomical charts did not distinguish the large and small intestines. He did not believe, in fact, that they were morphologically or physiologically dissimilar. What made them utterly different was that the large intestine was responsible for absorbing and excreting solid wastes, while the small intestine performed those functions for fluid wastes.

He emphasized that this crucial difference would be undetectable in a dead body. Figure and appearance could be significant only to the extent that they were related to function. Sano, unlike the *Koihō* radicals, had no use for pure empiricism. "The observation of two obvious facts is of much less value than groping speculation....even a child is as good an observer as an adult." A scholar who refrains from tracing speculatively the connections between form and function is no better than a child.

After accurate European anatomical charts were introduced to China, even those traditional schools of medicine which admitted anatomy as the basis of surgery (an undeveloped art in the Chinese tradition) still adhered to an energetic and functional point of view as the basis for internal medicine. But an idea shift to a solidist approach had at least begun.

It would be a mistake to see this shift purely in terms of the increasing accuracy of anatomical description. The *Koihō* school, like Western empiricists, could not do away with metaphysical entities, but rather depended upon them without acknowledging them. Their physiological and pathological ideas were not only less explicit than those of earlier speculative Chinese medicine, but a great deal less sophisticated. The move toward solidism was not a rejection of models, but the construction of a new model.

Yoshimasu Todo, for instance, rejected the elaborate Chinese theories, but was unable to translate his solidist way of thinking into diagnosis without the aid of a theory that Chinese doctors would have considered primitive: he saw all diseases as the action of one fundamental poison on the various organs and tissues of the body. This was not really a pharmacological theory about the effect of poison, but merely a rationale for locating the part of the body on which treatment should be concentrated. He also rejected the traditional pulse diagnosis, which had served as a way of reading functional characteristics of the *ch'i* circulation. Thus faced with the problem of how one was to determine the condition of the internal organs without dissection, he did not so much do away with pulse reading as substitute for it. This technique had been used in a very limited way in traditional medicine, chiefly to determine whether existing abdominal pain increased or decreased when the belly was pressed. Yoshimasu enormously increased its importance as the most direct way of learning about the conditions of the internal organs, and thus founded a Japanese diagnostic tradition which still flourishes among traditional doctors of today.

The solidist tradition that *Koihō* school began eased the way for Western anatomy. In the second half of the nineteenth century, Sugita Genpaku took up the study of anatomy because it seemed the most tangible, and therefore the most comprehensible, part of Dutch medicine. Following the solidist breakthrough, it was the successors of Sugita in medicine who studied physics and chemistry and opened up the world of modern science. The Copernican influence was minor by comparison, because the Japanese cosmos had not been defined by religious authority. The impact of anatomy challenged the energetic and functional commitments not only of medicine but of natural philosophy. Its effect was bound to be revolutionary.

Medicine and Science after the Kaitai Shinsho

Publication of the *Kaitai shinsho,* the first Japanese astronomical treatise based directly on Western materials, not only led to recognition that Western knowledge of the interior of the body was superior to that of China, but it provided a new paradigm for Japanese science.

Once the Japanese were prepared to compare accounts of the interior of the body from a purely morphological point of view, the superiority of the West became only too obvious. Chinese-style conservatives could dismiss European anatomical charts as superficial, but they could not convince others.

The first Japanese to realize the power of Western anatomical knowledge naturally assumed that the European system was also therapeutically more effective, although there is no reason to believe that this turned out to be the case. There is very little to choose between the internal medicine of the various high civilizations before the end of the nineteenth century, and the more frequent resort to surgery in the European tradition could hardly have let to consistently higher recovery rates before the introduction of anaesthesia and asepsis. Some scholars give the edge to Chinese internal medicine because it tended to use milder and less drastic drugs than were prevalent in Europe. It is ironic that one of Yoshimasu Todo's innovations was the frequent use of poisonous drugs to "fight poison with poison."[21]

Among the great diversity of schools in Japan there were eclectic groups who prescribed both Chinese and Western drugs for a single symptom. But that was about as far as eclecticism could go. The views which underlay Chinese and Western medicine, or even *Kokhō* medicine and practice of a more traditional kind, were irreconcilable.

It was quite possible to introduce European data into traditional calendrical astronomy without challenging the paradigm on which it was based. An analogous accommodation was impossible in internal medicine for there was little overlap of their conceptions of relevance. Acceptance of the European way of looking at the body came only with the publication of *Kaitai shinsho*. The *Koiho* school can only be considered a vanguard in this scientific revolution. Such a transition did not take place in China because Chinese maintained their traditional medical world view much more rigidly than did the Japanese.

An important characteristic of early modern science is mechanical reductionism, in which every phenomenon could be explainable in terms of matter and motion. This reductionism gave birth to the positivists' hierarchical arrangement of the sciences. Auguste Comte ranked the abstract sciences in the order in which he believed they would be entirely quantified, beginning with mathematics, astronomy, physics, with sociology at the end of the list. At about the same time Japanese physicians were constructing an analogous but very different schema.

After the publication of the *Kaitai shinsho*, some medical practitioners, exploring the newly available writings on European physical science, recognized and responded to its reductionism. In the prefaces to Aochi Rinso's *Kikai kanran* (1825) and Kawamoto Komin's *Kikai Kanran kogi* (1851) the authors claimed that physics must be the basis of medicine and the other practical sciences. Kawamoto described a hierarchical order from physical to physiology and then to pathology, and eventually encompassing practical therapy. It is not clear how seriously Kawamoto's fellow practitioners took him. It is likely that they saw no clear role for physics in medicine, except perhaps for embellishing prefaces as disquisitions on *yin-yang* had done in traditional books of therapy.[22] Physics and chemistry were introduced into Japan by European medical men only for their limited direct value to clinical medicine, just as anatomy, physiology, and pathology were subordinated to the same use. Hoashi Banri, a natural philosopher whose background was in medicine, was disappointed and disillusioned with Western science when he examined books on microscopy and chemistry and found that they were of no help in the understanding of drug therapy. They underlay techniques of measurement in *materia medica*, and of extracting the active essences from herbs. Those were the basis for their initial study by physicians. Their value as a new philosophy was to unfold only gradually.

Social Status of Medical Practitioners

In Japan mathematical astronomers were minor bureaucrats, responsible for preparing the national ephemerides. Although they were the earliest to recognize superior aspects of Western science, they overlooked its basic paradigms and remained within the traditional mold. Their academic style, as we have seen, tended to be greatly shaped by their proximity to sources of power.

Medical practitioners, who first took up the challenge of the Western sciences, were the largest scientific profession during the Tokugawa period. Medicine, unlike astronomy, was a private concern, and thus free of one kind of constraint upon the response to new ideas. Because there was no public health programme at the time, medical practice was essentially a relationship with individual patients. There was usually a private physician in each community. The samurai class had their government doctors and fief doctors, and townsmen and peasants had their local practitioners. But this profession was not tied together or controlled by the central government. Although Edo, as the seat of the shogunate, was a centre of professional activity, the important schools of medicine were scattered as far as Nagasaki. This decentralization made medicine one of the few geographically mobile professions in Japan. Toward the close of the Tokugawa period, in the first half of the nineteenth century, it became rather conventional for medical students to visit the various centres of instruction and to be initiated into the different schools of clinical medicine. Moreover, practitioners who distinguished themselves were often called to serve the fief governments or the shogunate. Although the stipend they received was small, the prestige they gained raised their fees in subsequent private practice. The competitive market for medical practices in Japan was most untypical of the society as a whole. Western-style physicians took advantage of it as they moved into a practice that had previously been monopolized by traditional practitioners. There is a loose analogy between this situation and that of the nineteenth century German academic market described by Joseph-Ben-David.[23] In Japan, furthermore, there was no guild organization of physicians to limit or control competition.

Unlike the medical profession in Europe, which was well integrated in society and could reproduce itself in the universities, Japanese doctors were socially marginal. Their mobility was anomalous in a society where status was supposed to be hereditary and where the only elite was supposed to be the hereditary samurai.

The Taki family, hereditary physicians to the shogunate government, once tried to centralize medical standards by founding an official medical school which all sons of doctors were to attend, and at which they were to be examined for a licence to practise medicine. This attempt failed, in contrast to the ease with which central authority was established in other fields. The main impediment to uncontrolled competition in medicine was not guild or government organization but the hereditary system on which the Tokugawa social order was based.

The samurai, the military elite, inherited ranks and stipends that depended upon the contributions of their ancestors to the foundation of the Tokugawa Shogunate in the mid-seventeenth century. Merchants, artisans, and others did not depend upon fixed stipends as the samurai did, but their social class was fixed through inheritance. This system could not easily find a place for intellectual professions, which could flourish only in situations where advancement was based on talent rather than on birth. In the Tokugawa period there were three such professions : Confucian philosopher, medical doctor, and mathematical astronomer. In all of them people of outstanding ability often remained subordinate to incompetent samurai, and if they worked for the government, received lower stipends.

Attempts were continually made to subordinate these professions to the hereditary principle. It was expected, for instance that the son of a doctor would eventually be registered as a doctor, regardless of how little intelligence or motivation he might have. At the same time, the shogunate and the fief governments needed talented professional family from the government to adopt a gifted youngster.

Government employ was only one possible source of income for a physician. Osaka for instance was famous for a medical centre mainly patronized by merchants. The clinical experience of the therapeutist mattered a great deal more than his formal education. The son of a village doctor would begin by working with his father, then spend many years as an apprentice to more distinguished doctors, and finally return to his native village to take over his father's practice. From generation to generation the number of patients would gradually increase until that medical family was expected to provide family doctors for the whole village. Because such hereditary traditions were quite independent of the government hierarchy, doctors were among those most responsive to liberal thought in the period shortly preceding the modernization of Japan. Mathematical astronomers were not independent in the same way.

Although Confucian scholars formed a professional group, they lacked the social mobility and economic security of physicians. Their official social status was a good deal higher, but the revenue that they might earn by private teaching could not compare to the fees of the doctor. In essays of the Tokugawa period the social commitments of the two are often compared, to the detriment of physicians. Confucianists are concerned with society as a whole, and physicians only with individuals; Confucianists deal with the mind, and physicians only with the body; Confucian scholars are generally poor, while physicians gouge their patients and live in luxury. It is clear from such remarks that establishment values favoured the Confucianist, and found the practical skills of the doctor a little too close to those of the artisan.

This difference should not be overstressed, since Chinese-style medicine emphasized that practice must be based upon Confucian ethics. Young men who chafed under this devaluation of medicine as a pursuit in its own right were especially attracted to Western medicine, which seemed devoid of philosophic and moral constraints.

Those attracted to intellectual pursuit found it most attainable if they left clinical medicine and became a teacher or public figure. Doctors of Western-style medicine gradually distinguished themselves into two groups: one which concentrated upon medical practice and the second which mainly taught foreign languages and Western science. In the difficult international situation after the Opium Wars of the early 1840's, it was from medical schools in the latter group, such as that of Ogata Koan that there appeared political activists like Hashimoto Sanai who renounced their inherited professions to lead political careers.

Of the three intellectual professions of the Tokugawa period, only physicians were able to form an independent stance by which they could view the world in a new light. Naturally, it was they who brought modern universal science to Japan. But their independence was bought at the cost of alienation from the true sources of power in Japan.

MATHEMATICS

Preliminary Remarks on Scholarship and Art

In Japan, the interest in the traditional Japanese mathematics *(wasan)* grew over time and spread into local areas since the seventeenth century. Mathematics was enjoyed by leisured groups in the same fashion as the flower arrangement or the tea ceremony. In fact, modern historians of Japanese mathematics have commonly observed that *wasan* was more of an art form than a field of scholarly inquiry.[24]

While *wasan* may be considered an art form, it is by no means easy to distinguish art forms *(gei)* from scholarship *(gaku)*. Activities which individuals consider scholarly in nature are not necessarily so regarded by society. Whether various activities are considered scholarly or not, depends on the views of certain social groups in specific locations during a particular period. Such views may also depend on the value standards of intellectuals and may be influenced by the presence or absence of official authorization as well as by popular impressions.

I shall not attempt a conceptually rigorous definition of scholarship and art here, but merely note that scholarship is usually thought to have some public function while art forms are regarded as private indulgences which may or may not have significant social value. This distinction between art and scholarship, at least, was consciously employed by many writers during the Tokugawa period. For example, Seki Kowa, often called the *sansei* or "sacred mathematician" for creating the dominant *wasan* paradigm, wrote on a student's diploma in 1704 as a way of conferring legitimacy on his field: "Mathematics, after all, is more than an art form."[25] He thus refused to define mathematics as an art and tried, instead, to establish it as a dignified, prestigious form of scholarship. He even referred to mathematicians as "scholars."[26] Among themselves mathematicians acted as if they were pursuing an art form but in front of non-mathematicians tried to present their work in another light as a way of giving it prestige. Some kind of legitimation was necessary for mathematicians to succeed in this effort. While art does not require legitimation, scholarship does and there had to be some basis on which to differentiate the one from the other. And the evidence of this concern for social legitimation is best seen in Seki's introduction.

Introductions to mathematical treatises did not usually reflect the authors' personal views since they were written by Confucian scholars according to a fixed, decorative pattern as a way of borrowing Confucianism's prestige. However, these introductions had no connection, whatsoever, with the highly technical matters discussed in the main text and were essentially empty, formalistic phrases.

The basis for the contention that contemporary people should respect mathematics was simply its high status in antiquity stemming from Confucius' esteem for it, and from its designation by the sage as one of the six arts. This was a Confucian form of legitimation, and it derived from the conceptions of classical scholars. But the mathematicians of Tokugawa period themselves were generally socially marginal curiosity seekers, and thus did not care whether mathematics had ever been one of the six classical arts or not. During the more than two thousand years since the time of Confucius, Confucianism had become securely established, but astrology, mathematical astronomy, medicine and arithmetic had come to be considered lesser crafts and were consigned to a peripheral, low-level status in the hierarchy of disciplines. Among them, arithmetic, which was associated with such mundane matters as surveying and tax collecting, was assigned a status well below that of astrology and even further below that of mathematical astronomy which described the principles governing the heavens and earth. Even so, arithmetic had a guaranteed — if low — position in the Chinese bureaucratic system, unlike chemistry or various other fields; and in Japan's pre-feudal period there were also doctors of mathematics and official arithmeticians.

During the Tokugawa period, however, mathematics was not formally recognized in the governmental structure. But the Tokugawa mathematical tradition existed entirely in the private sector and had no link to the pre-feudal tradition of the arithmetical doctors. Historical awareness of founding fathers did not antedate the Tokugawa period. Consequently, Japanese mathematicians, unlike the school of such Ch'ing mathematicians as Mei Wen-ting, did not try to use the ancient designation of arithmetic as one of the six arts as a basis for defining their own identity.

The Pythagorean belief that numbers permeate all objects in space or constitute the basic principles of the cosmos was certainly part of the Chinese mathematical tradition; it was specifically the creed of Chinese diviners and specialists in *yin-yang* cosmology. This kind of belief was often used to justify the activities of mathematicians. But this argument was more commonly espoused by cosmologists, astronomers and specialists in calendrical science than by mathematicians themselves. The Pythagorean attempt to explain the cosmos by numerical cycles and the cyclical world view as such did exist in the Chinese tradition into the Han period; but as astronomical observation became more precise, cycles came to be described algebraically using fractional tables, and this cosmological view collapsed.[27] Specialists in calendrical science in the T'ang era did not consider expatiating on the cosmos a legitimate part of their work and rejected cosmologizing altogether.[28] In the Sung period, cosmology once again became a subject of discussion among Confucian scholars, but the calendar makers were inclined to think that Chu Hsi "talked nonsense because he did not understand mathematics" and generally refused to take up the problem.

During the earlier period Japanese mathematicians frequently took up problems posed in calendrical science and this was especially true of their founding father, Seki Kowa. As normal science mathematical activity continued, despite that pragmatic orientation disappeared from the *problematique* of Seki's followers.

It is said that people like the mathematician Wada Yasushi made a living by practising divination during the Tokugawa period but this report may be based on a popular misconception deriving from the fact that diviners and mathematicians both used *sangi* (computing rods). In fact, mathematical calculations and divination based on calculating rods were completely dissimilar.

Mathematics during the pre-feudal period was completely practical in character and thus had legitimacy as a form of scholarship. Even in the Tokugawa period one finds appeals to practicality in prefaces to mathematical works designed for such practical purposes as surveying; these appeals were apparently accepted at face value. However, practical mathematics did not interest most mathematicians.

Wasan lost even its practical character and became explicitly non-utilitarian in character.

The Social Position of the Tokugawa Mathematicians

Whenever scholars demand legitimacy from society, they display a sense of mission which reinforces their commitment. This sense of mission is associated with the rise of professions which in Western society are intellectually based associations somewhat detached from worldly gain. Theology, law and medicine were all recognized as such in medieval universities. In the early modern period scientific researchers and engineers were also recognized as professions. The largest profession in Tokugawa Japan was probably the Confucian scholars. One might also refer to physicians, astronomers and specialists in calendar-making as professionals. But whether the mathematicians can be called professionals or not is a difficult question to answer.

A sense of mission included a desire to achieve some lofty objectives beyond immediate personal interest. Such strange personalistic objectives as scholarship or science for their own sake seemingly represent an early modern form of consciousness that developed after the emergence of scholarly elitism, especially that of the German-type universities. Prior to the time that this modern attitude became established, a field would not be granted the status of a scholarly discipline unless the established political administration chose to recognize it; and in such earlier times the government alone decided what had prestige and what did not.

The popular image of mathematics was that of the abacus. The social position of mathematicians was probably based on demand for their services in teaching people how to use it. But daily use of the abacus did not require anything like the elaborate mathematical technique of the mathematicians. In merchant families abacus manipulation was considered a form of spare-time study. Apprentices were introduced to it by the head of the business. There was a saying to the effect that, "While use of the abacus is one of the most important things a merchant must learn, he should not take it too seriously. Excessive study will hurt business.[20]" Studying mathematics to a greater extent than business required was generally forbidden as a form of dissipation. Some mathematicians managed to make a living by opening schools. The majority of such schools were run by masterless samurai. The mathematical training they gave usually stopped with simple arithmetic and the calculation of interest rates. Thus, the *enri* calculus, which included the most sophisticated problems studied by the mathematicians, was not generally taught in these schools.

From the government's point of view mathematics was closely associated with simple calculation and land surveying. But in the *Ryochi Shinan* (Introduction to Surveying) one finds statements like the following : "People who study mensuration say that not all mathematics is intended to be used by surveyors. According to them, there is nothing about mathematicians' theory that is contradictory to mensuration; but if you look at their work, it seems too much involved in mathematical theory and divorced from practice. And in general mathematicians' talk about surveying is all of this sort".[30] Or: "Mathematicians' techniques are a distraction with no utility whatever".[31] The traditions of the academic mathematician and of the practical surveyor were quite distinct.

Astronomy offered mathematicians far more sophisticated problems than surveying. Examples taken from traditional Chinese astronomy would include indeterminate procedures for calculating grand conjunctions, transforming equatorial into ecliptical coordinates on the sphere, and interpolation procedures for handling the equation of the centre. The trigonometry and algebra that came to Japan with the Jesuits' later transmission of European astronomy could also have opened up new mathematical vistas. And there were problems in navigational astronomy which mathematicians like Honda Toshiaki and Sakebe Hironao actually did investigate. But these topics were all considered astronomical problems and as such were separated out from the mainstream of mathematical activity.

In the domain schools, mathematics seems to have become part of the curriculum from about the 1780's.[32] Textbooks published by the various domains also appeared. They seem to have included problems in applied mathematics taken from surveying, calendrical science and navigational astronomy. Some mathematicians served as *Bakufu* astronomers and others worked as accountants or surveyors in the domains. But they saw their public duties as separate from their research in mathematics and considered the latter private activity. Astrologers and astronomers employed by the various domains all used the algorithms of *wasan* mathematicians when they calculated. But one finds no significant public comment on the *wasan* tradition in works by astronomical specialists. This may have been due to the bureaucratic psychology: by virtue of working in the public sector they simply gave no thought to the work of mathematicians who belonged to the private sector. The result was that mathematics had no real home in the government.

Nor did mathematical research have any base in the occupational system. Mathematicians' research activities were a part-time activity, separate from their occupations which, in fact, ran the gamut from warrior to farmer, artisan or merchant.[33] The orthodox Seki school was typical in this sense.

In general, mathematicians' greatest achievements were made in their early years, but the *wasan* mathematicians were most active in their later lives.[34] This was due to *wasan* mathematics' shallow roots in the education system, the inadequacy of the available textbooks, and the extraordinary time required to become proficient. All of these factors surely had an important impact, but an even more influential factor may have been that the time and money required to indulge in mathematical study only came with the circumstances of later life. Anyone who gave up his regular occupation to devote time to mathematics had a very difficult time of it; and because of that it was very difficult to find the money for publication costs. In particular, samurai employed in the government had scruples about participating in such activities and for the most part only published mathematical works after retiring from the office.

The prestige of any field of scholarship is bound up with social status of those engaged in it; and from that point of view there is little reason to think that the mathematicians were particularly respected by society in general. In China, Chu Shih-chieh and Ch'eng Ta-wei, authors respectively of the *Suan-hsueh ch'i-meng* and *Suan-fa t'ung-tsung* from which *wasan* mathematics was derived, made a living as itinerant teachers. And in Japan also, there were mathematicians who travelled from one place to another and received support from wealthy patrons of mathematics.[35] In point of livelihood, these intellectual salesmen were no different from travelling artists.

Wasan mathematicians had no recognition from the establishment. There was no system for training or recruitment. The occupational base consisted of nothing more than the totally inadequate patronage of a few wealthy individuals. As a result, there was no agency to defend mathematics *vis-a-vis* society. The clandestine nature of their organizations did not allow *wasan* mathematicians to defend the scholarly aspects of their work effectively and they received little or no social recognition. Nevertheless, they showed greater signs of activity in certain respects than an amateur gathering like the Royal Society did.

The artistic character of *wasan* mathematics helps to explain this fact. In publishers' catalogues of the Tokugawa period, books on *wasan* were classified with materials on the tea ceremony and on flower arrangement, which suggests that *wasan* was mostly viewed as a popular art. However, art involves the pursuit of aesthetic pleasure while purely intellectual matters will be regarded as scholarly in nature. During the Edo period there were several pursuits which were not scholarly occupations and had no academic prestige : games like *go* and *shogi* or Japanese chess, for example, and it was probably these activities which in conjunction with poetry and the fine arts encouraged the development of *wasan* mathematics and encouraged its diffusion.

The Internal Logic of Wasan Development

What was it then that distinguished *wasan* from poetry and the arts in general? In what sense was it a scholarly form rather than an artistic one? While it would not be quite accurate to say that *wasan's* methodology was that of a modern discipline of science, it definitely did come closer than any other field of inquiry existing during the Tokugawa period. It had, for example, a way of asking questions that was very similar to that of modern science. Thomas Kuhn states that all sciences begin with a paradigm or model for raising and answering questions in terms of which scientific progress will necessarily occur.[36] And *wasan* conformed to this pattern rather well. Not only was it a discipline with an extensive field of knowledge, it stated its problems and questions in a precise way. Among the disciplines of the Edo period, *wasan* and calendrical science had a more scientific way of raising questions than did the moralistic schools of philosophy, the pragmatic approach of the administrative class or the classical medical tradition with its emphasis on treatment. And since the questions raised in *wasan* were not limited by tradition, it can also be considered modern or scientific in this way, though the same was not true of mathematical astronomy in Japan.

Wasan mathematics developed a unique custom in its formative period consisting in the posting of mathematical problems called *idai* (Bequeathed questions). A mathematician would pose scores of problems of several kinds in the latter part of a book and then publish it. Another mathematician would post answers to these problems and present his own in the same manner. According to convention, yet a third mathematician would post answers to the second set of problems and issue his own in relay fashion. This interest in mathematical puzzles greatly stimulated the formation of *wasan* groups. They were influenced by Chinese experience, but there does not appear to have been anything like the custom of posting *idai* in China. The tradition began with twelve problems from the *Shimpen Jinkoki* published in 1641. A succession of mathematical lineages soon developed and reached a peak during the life of Seki Kowa. Certain themes continued to appear in these problems which passed through a number of phases. Practically all of the important problems in the history of *wasan* date from the period of these *idai*.[37]

Mathematics has a strong puzzle-solving character and problems are readily invented. In fact, pure mathematics can invent problems freely since the objects of its inquiry impose no definitional limitations on it, unlike the natural sciences which only take up problems posed by nature or by society. Almost limitless possibilities are concealed in its way of answering questions. Indeed, by giving free rein to their imaginations, mathematicians can create worlds of their own without recourse to the logical forms which limit ordinary language.

During the early period there were two types of *idai*: problems used in daily computation and those relating to geometry. In the Chinese mathematical tradition which influenced *wasan*, practical problems were more common, but later on more whimsical problems were added. The *Jinkoki*, which defined the popular image of *wasan*, also emphasized practical problems, but as *idai* got passed on there developed a trend toward problems of a purely intellectual or recreational character among the inheritors who were both enthusiastic puzzle-solvers and uninhibited by utilitarian constraints. The puzzle-like character of *wasan* mathematics made this entirely predictable, and given the sense of problematique practitioners were not inclined to select problems with practical applications. Moreover, other factors reinforced the same trend. Once a problem had been abstracted in the form of a diagram, people did not concern themselves with its utility and could enlarge or develop it freely. The purer their mathematical character and the greater their detachment from practicality was, the greater the enthusiasm was with which problems were received. We shall later consider a typical example, the *yojutsu* (Packing method) which involved fitting various large and small circles into a triangle.[38]

It also seems significant that *wasan's* impracticality precluded any links to mechanics or optics such as was true of mathematics in the history of Western science. This point at least has been noted by historians of *wasan* who suggested that the *idai* phenomenon of the seventeenth century was probably responsible.[39]

Commerce, surveying and calendar-making did provide examples of possible practical applications. However, the first two did not offer very sophisticated problems and the degree of precision required in their calculations was much less than that demanded in the theory of errors or in higher degree equations. Calendar-making, of course, was an exact science but the major problems presented by the existing Chinese calendar had already been solved by such eminent mathematicians as Seki Kowa and Takebe Katahiro. In theory, the Five Star Law of planetary motion should have been able to offer problems fully as interesting as the theory of epicycles in the history of western astronomy, but the Japanese art did not emphasize planetary movements, so they were not investigated very thoroughly. Ultimately the absence of kinematic and dynamic problems in Japan's scientific tradition handicapped and retarded *wasan's* approach to analysis and proved decisive in its race with the Western tradition. From about 1650 to the early eighteenth century, when *idai* were popular, the natural sciences did not develop to any extent. Science from the west had yet to be imported. It was during this period, and from these *idai*, that *wasan* mathematics created and established its significant problems, though in certain respects prematurely. The topics investigated were taken from such concrete problems as the volume of a rice bag or measuring cup they were often focused on diagrams of circles or cones which had to be solved for a numerical value. As this trend progressed, the pure enthusiasts gave little thought to the relationship between observation and its practical meaning, but simply invented fictitious problems whenever they wished. Once they discovered a strategic or paradigmatic problem, practical problems of astronomy, trigonometry or Western logarithms were no longer considered legitimate. The eccentric genius Kurushima Yoshihiro once wrote:

"In mathematics it is more difficult to raise a problem than to give the answer. Only mathematicians who cannot invent problems borrow them from calendrical science".[40] In short, the idea that looking for subject matter in society or nature was undesirable had already developed in the eighteenth century when the notion of mathematics for its own sake emerged.

In tackling the practical problems of applied mathematics, the important thing is to obtain an answer stated as a numerical value. Given the determination of topics in this field by social or natural conditions, it is entirely appropriate that obtaining numerical solutions should be considered more important than inventing problems. On the other hand, question-asking is essentially unlimited in pure mathematics, as Kurushima implied, and is necessarily considered supremely important. As with crossword puzzles, inventing the question is more difficult than supplying the answer. Only one person invents a problem and many people will try to solve it. To the extent that a single problem-inventor controls the actions of many solvers, he may be considered superior. That one person paves the way by inventing a problem while others follow in trying to solve it is part of the normal science tradition and further underscores the process by which normal science is conducted.

The form of the problems at earlier time was not yet fixed. And when people invented problems, they did not simply adhere to those devised by predecessors. During that time there was a shift from various types of practical mathematical problems to pure mathematical problems and a convergence toward numerical solutions to diagrammatic problems and a convergence toward numerical solutions to diagrammatic problems using the *tengen* algebra (algebra based on the use of computing rods).

As time passed, the problems became more intricate and multi-faceted. Inventors did not simply present problems which they themselves had already solved, since other mathematicians considered that too simple and even foolish. There was an emphasis on solving problems by some unusual means or in presenting problems to which it was not known whether a satisfactory solution existed or not. People would take up a mathematical challenge and expend all their energy trying to solve it. The way *idai* were presented gave an enormous stimulus to the competitive spirit of later mathematicians. Problems that were difficult to solve constituted a never-ending challenge. There were also, of course, examples of this in the history of Western mathematics, which had continued to engage the interest of mathematicians.

But as problems became more complex, impossible problems appeared and mathematicians began expending excessive energy to little effect. Such problems could not constitute paradigms, could not lay the groundwork for normal science, and did nothing more than create confusion. Indeed, the confusion itself suggests that Japanese mathematics was at a pre-paradigm stage. What really gave Seki Kowa his enormous reputation, in consequence, was his creation of the basic paradigm both for posing questions and for answering them in an intellectual setting where almost total confusion had prevailed earlier.

After the importation of the *tengen* technique, changes took place in the way questions were posed through the *idai*. In the earlier period, *idai* were highly diverse and multi-faceted but now came to emphasize equations of higher degree that were difficult to solve. Problems, which today can be solved by the use of several simultaneous equations, could only be solved then by transforming them into a single equation of higher degree by the use of the computing rods. But, at that time, confusion was made all the worse by the popularity of *idai* deliberately designed to solve more and more complicated problems by changing everything into a single equation with increasingly higher degrees. These problems were known as *handai* (cumbersome problem). This tendency might have represented an aberration in the proper development of mathematics but it did prompt Seki Kowa to introduce an important innovation, namely, the *tenzan* algebra, a system for expressing unknowns in symbols — A, B, C, so as to use simultaneous equations freely.[41]

Seki also devised a system of equations based on the existence of negative and imaginary roots. *Wasan* had inherited from China's pragmatic mathematical tradition the idea that an equation can have only one root. This seems to have come from the idea that in problems derived from a diagram, a root should be represented as a line segment. As a consequence, one did not think about or try to interpret the meaning of negative or imaginary roots when using them. *Wasan's* characteristic way of handling the matter was rather to focus attention on the impossible problem which produced the negative or imaginary roots, then by transforming and correcting the problem, make it into one which had a proper solution. Imaginary roots as we know them today are referred to by some people as *musho*[42] but there is some doubt about whether this term really captures the mathematical meaning. Rather than thinking of the term, negative or imaginary root, as something other than a true mathematical entity, it would seem appropriate to look at *musho* as implying nothing other than the non-existence of a root. Re-stating a problem or changing its form in the search for roots not only restricts problem delineation, but also fails to prove the existence of negative roots as such. Consequently, during Seki's lifetime the movement toward imaginary or complex numbers in *wasan* was permanently turned aside.[43]

Seki's writings on the theory of equations set forth *wasan's* orthodox way of asking questions. These writings on the theory of equations were included in a seven-volume book transmitted with great secrecy by the Seki school and appear to have been studied and passed on by pupils who were eminent enough to devise new problems themselves. The *tenzan* algebra had laid down guidelines for solving problems. And since these had previously been fixed, one may say that Seki fully paved the way for *wasan's* later development.

Of course, Seki Kowa was not the only outstanding mathematician of the period. He certainly had the intuitive sense of a genius; but if he had been an isolated figure too far ahead of his followers, the paradigm he laid down would not have been taken up nor have paved the way for normal science. There would have been no Seki school. During Seki's lifetime his school was carried forward by such eminent disciples as Takebe Katahiro and Matsunaga Ryohitsu, and Seki was placed on a pedestal within the tradition. One may suppose that the special treatment accorded to him was instrumental in establishing the diploma system.

Seki Kowa left answers to a large number of *idai* during the period of their greatest popularity. In fact, the theory of equations seems to have been born from the many different kinds of *idai* he considered. There is no indication, however, that Seki himself left behind any *idai*. After his time the practice of issuing them declined considerably. Their frequent appearance corresponded to a pre-paradigm stage in the delineation of mathematical problems. *Idai* were scrutinized and re-stated according to the principles of equation theory, and the significant ones were passed on. The paradigm emerged when the techniques for solving these problems by the *tenzan* algebra were given; and at that point a way of asking and answering mathematical questions emerged which was quite different from the pre-paradigm situation. Creation of the paradigm was not the achievement of Seki Kowa alone but he happened by circumstance to be given credit for it, and was in fact at the centre of the *wasan* tradition. Since the procedures for raising and answering questions were fixed, it was meaningless to set forth a large number of *idai*. With the problematical issues clarified, subsequent mathematicians quickly emerged to resolve them. *Enri* (principle of circle) calculus was one of the problematical areas that attracted attention. (This technique developed from the mathematics of the circle and later gave rise to the development of linear progressions and analysis.) It was either the creation of Seki or of his leading disciple Takebe Katahiro. *Enri* calculus was not applied only to issues involving the circle but to curves and curved surfaces in general.

Mathematical problems are not limited to those posed in nature or by society. But mathematics' pattern of development will change according to the kinds of problems taken up. Different choices of problems may create different mathematical worlds. Consider, for example, the calculus which developed from problems concerning the arc, an important topic in astronomy. It involved problems of mensuration and in its results agreed completely with the Western-style calculus. However, the course it followed in getting there was completely different from that of Western mathematics which began with problems in dynamics. We should say, on the other hand, that problems relating to dynamics offered mathematics greater scope for development than those concerned with arcs and circles, simply because time was involved. Thus there were limits to the kind of problem development possible in this area.

Another stimulus to the development of *wasan* was the *sangaku* (mathematical tablet) form that came after the *idai* tradition. These included both problems and answers and were offered at shrines. The best mathematicians made their accomplishments known through books, but it was largely the custom of *sangaku* which supported the activities of the *wasan* enthusiasts. That *wasan* was a hobby which cost money to pursue is best shown by the elegant diagrams which embellished such work. In fact, the offering of *sangaku* had a strong attraction for local gentlemen over other art forms — drama, music, poetry — as a way of making their work known; and their frequent indulgence in it shows a desire to keep themselves on more or less permanent view.

The most important kind of problem taken up in *sangaku* was called *yojutsu* which involved the attempt to inscribe the largest possible number of small circles in a larger circle. Public interest was limited to *yojutsu* decorated with designs of circles and squares. The pictures were intended, so far as possible, to give people the impression that the designer had obtained the solution to some difficult problems through a complex diagram. Thus, while *yojutsu* seemed to concern itself with very difficult problems, its emergence was not all that significant mathematically.

When *yojutsu* first began to flourish, there was a tendency for different techniques to compete with each other in solving what was essentially the same problem. Later on, however, the variety of problems was exhausted, the method of solving them became settled and there was a tendency to focus exclusively on problems to which the same technique could be applied. In any event, problems became more and more complicated while technique scarcely developed at all.

Enri calculus and *yojutsu* both developed as normal sciences but in somewhat different ways. With the *enri* calculus there was a step-by-step development. That is, when one problem was solved, its result was used to solve a problem requiring even more extensive investigation; and in the process there appeared what might be called sub-paradigms. *Yojutsu* in principle, was a problem-solving technique in the same sense but its pattern of development amounted to nothing more than a series of transformations and variations upon problems. Moreover, its technique was not based on a demonstrational logic in the Euclidean style, and did not aspire to general principles of problem-solving. During its two hundred year history, *yojutsu* produced several byproducts but its reliance on casual inspiration as in puzzle-solving ranks it well below *enri* calculus in scholarly value.[44] One could only have referred to *yojutsu* as a Japanese form of geometry if it had gone beyond mere puzzle-solving and achieved a general methodology. In fact, it should go in the direction of analytical geometry but its techniques were not strictly logical and it did not evolve to that degree. However, because it was a puzzle-solving technique, it did become an acceptable form of recreation for the amateur *wasan* enthusiasts.

Wasan mathematicians apparently did not fully realize the importance of logical foundations, but rather valued insignificant, complicated and overly elaborate problems which were prestigious and worthy of attention. It is a well known story that when Euclid's *Elements* first came to Japan, the simplistic, poorly developed and inferior character of European mathematics vis-a-vis *wasan* could be determined just from looking at its pictures. One might even call it an art form whose major goal was the refining of trivialities.

Mathematics, especially a pure form like *wasan,* differs from the natural and social sciences in the absence of checks imposed on it by the objects it investigated. It does not follow the kind of development characteristic in a discipline like physics where an accepted interpretation of some phenomenon can change completely during a scientific revolution. Non-Euclidean geometries can co-exist with Euclidean geometry and the replacement of the latter by the former is far from inevitable. In fact, non-Euclidean geometries are not so much replacements for Euclidean geometry as a series of variations upon it. But unless one counts such trivialities as different assortments of diagrams in *yojutsu* problems, one would have to say that *wasan* had very few basic variations, and in particular, almost none that were conceptual in nature.

Perhaps the basic conceptual poverty of *wasan* can be explained by the derivative character of the culture in which it developed. Japan, after all, had what was essentially an imported culture in the sense that most of its basic cultural paradigms were extraneous in origin. Highly refined art forms were created on the basis of these paradigms and the lack of attention to the attendant theoretical foundations may have precluded a reconsideration of basic paradigms in mathematics just as it did elsewhere. By contrast, the Chinese did consider the theoretical foundations of various disciplines, though they did so in their own particular way : by inquiring, as with astronomy, into the matter of its historical origin. Yet in Japan, *wasan* mathematicians raised neither the question of historical origin nor any other involving the theoretical foundations of mathematics.

Given that Japanese astronomers and physicians constantly compared China and Europe and took from either what they judged to be good, why did the mathematicians alone remain shut up in their own world? In the first place, there was a difference in disciplinary structure between medicine or the natural sciences and mathematics. The former could readily determine what was better and what was worse merely by having both Eastern and Western examples before them; but in mathematics the objects of concern were not defined by nature or by society. Secondly, there was a difference in perceived objectives between the two. Because of its search for a "single truth", superior Western conceptions could more or less readily replace inferior Chinese conceptions in the more theoretical aspects of science. But, in mathematics, the emphasis was on building a world of abstract concepts and the belief that *wasan* and Western mathematics differed from each other only in style allowed the two to exist side by side. This difference was about like that between chess and Japanese *shogi*; that is, it was one of style and thus permitted coexistence. In this sense *wasan* and other forms of pure mathematics are closer to art forms than they are to scholarship. The *wasan* mathematicians thus did not feel threatened by the importation of Western mathematics and retired into their own artistic world. Comparing the applied mathematics of China which emphasized astronomical orientation with the pure mathematical tradition of *wasan*, however, one perceives a clear difference in the extent to which they considered the Western impact threatening.

Conclusion : The Japanese View of Law of Nature

Primarily through discussing practitioners of Tokugawa science, I have tried to describe the dominant view of science and of the laws of nature that existed in that period of Japanese history. What I have tried to argue in part is that aside from notions of law, Japanese in that period had a different conception of nature from what we have today.

Our present value-free conception of law in nature was actually produced in the nineteenth century university. Prior to the nineteenth century, intellectual activity pursued goals whose scope transcended that of modern value-free activity; in fact, modern concepts of the laws of nature were only applied in limited situations within this context. Similarly, in the Japanese case one readily discovers from the tone of the introductions to books in calendrical science, medicine, and mathematics, that the academic notion of science for its own sake did not exist in Tokugawa society.

In earlier times, science in the West was pursued on the assumption that its investigations would demonstrate the glory of God, while in Japan the ideology of Tokugawa science derived from Confucianism which emphasized individual moral cultivation and social pacification. Morality was the basis of law; laws of nature conformed to and were necessarily subordinate to it. Confucian moral thought, unlike Western counterparts, lacked the idea that man must find laws in culture and society because laws exist in nature. Thus, astronomy and medicine in Japan ultimately had to subordinate themselves to an essentially Confucian order of priorities in order to guarantee respect for their status as disciplines. Value-free pursuits like *wasan*, which diverged from moral values or had nothing to do with them, became isolated not only from the Confucian framework but remained merely a playful art form.

In its unconcern for moral values and occasional emphasis on laws *wasan* was the closest to modern science of all disciplines in the Tokugawa period. Takebe Katahiro consciously used the term "law" in his methodological writings, saying : "The establishment of laws provides the basis for technique; thus mathematics needs to have laws".[45] However, modern science's objectives simply consist in trying to establish or prove certain laws and nothing more. Neither does modern science have such grandiose and far-reaching objectives as alchemy which tried to prolong life indefinitely, or astrology which sought to predict the future course of nature and human affairs. It rather tries to achieve such objectives which are immediately possible. Modern scientists, unlike Shibukawa Harumi in Tokugawa Japan, avoid using historical changes in the celestial movements to explain changes in the heavens. They try to explain astronomy in mechanistic terms. And in coping with disease they emphasize solidistic explanations rather than presupposing a relationship between the human body and the vicissitudes of time as in the Heaven-Earth-Nature conception of Chinese medicine. From science's point of view it is difficult to predict the future of man, to prolong life indefinitely, to explain disease by the notion of *ch'i* or to interpret the heavens. Such paradigms make technical progress very difficult and for these reasons were abandoned by science. Affected by parochial variations and the ebb and flow of values at different times, Western science throughout history had sought patterns or common features in all phenomena. It has analyzed phenomena objectively and dispassionately while rigorously excluding value-laden admixtures from its purview. Similarly, commentators in Japan during the Tokugawa period also discussed the relationship of science with morality and it would seem that even modern scientists today cannot fully explain why or in what way the work they do should be considered value-free.

I do not believe that science in the Chinese and Japanese traditions converged into the same goal as Western science. Perhaps because Needham had fallen in love with Chinese science, he stresses China's world-wide priority in the history of discovery and invention and makes all sciences, whether Chinese or western, seem universal.[46] There is sufficient basis for his claims of priority, but when he compares and evaluates the past scientific and technical contributions of China and the West, he uses proximity to "today's standard", as the basis for evaluation. "Today's standard", however, is quite simply a Westerner's standard of evaluation. It may well be that to persuade ignorant Westerners of China's great contributions, Needham had no choice but to use this standard. But his desire to impute priority to Chinese science, one may say, seems to imply that Chinese and Western science had the same objective.[47]

There is a serious question, however, as to whether this was actually the case. Would Chinese science or that of Japan in the Tokugawa period have developed in the same direction as Western science in the absence of influence on them from the latter? Needham thinks that both were groping toward the same point of sublation, but can we reasonably assume the existence of such a point *a priori*? There seems to be a greater probability that the two were actually diverging in different directions. The intellectual framework differed from the one culture to the other and for that reason it would seem reasonable for the goals of science to have differed as well. One need not, from this point of view, be concerned with the problem of priority since even if Japanese science is set over against that of the West, the two were not following parallel courses of development toward some fixed, predetermined end.

Japanese science also developed within a framework of Confucian values. During the Tokugawa period it came into contact with the West and the direction in which it would necessarily develop was greatly affected by this experience. When Chinese culture was first received by Japan, science was included as part of the former's court culture or bureaucratic system; and Japan at that time was virtually a *tabula rasa* so far as the intellectual or institutional aspects of science were concerned. But by the time Western science came to Japan during the Tokugawa period, both the ideological and the evaluative aspects of the Confucian system had been modified to suit Japanese taste. (In brief, its naturalistic or philosophical aspects were de-emphasized while its moral dimensions were stressed). Western science was transformed into an art form according to the dictum of Sakuma Shozan about "Eastern morality, Western art forms". The result in the early Meiji period was a highly pragmatic science with utilitarian, materialistic features and quite lacking in moralistic connotations.

SCIENCE AND TECHNOLOGY IN MODERN DEVELOPMENT

Introduction

In those countries, which have emerged latest in modern form, science and technology have usually been introduced by the public sector and later transferred to the private sector when they have become productive. The Japanese experience in the late nineteenth century was typical and one of the earliest examples of this process. In the process of transfer to the private sector, there must have been a critical point at which it was determined whether imported science and technology could be confined to the public sector and then faded out, or would succeed in becoming established in the private sector to flourish in an indigenous and self-perpetuating form.

The next question is: Who was instrumental in initiating and transplanting science and technology and who supported them? We will discuss this in terms of the following tentative model:

1. First, there must have been a group of native people who could become professional scientists and engineers and act as leaders in the mass education of the people and in material construction.

2. Secondly, the standard of basic education level must have been substantially raised for a successful transfer to occur, since a modern state needs scientific manpower even among the lower strata of society.

3. Finally, in this process, social mobility begins and class differences tend to diminish. Modern science and technology are then in a true sense diffused and rooted among the populace, and its traditions become perpetuated.

The completion of these three steps may be the major stage differentiating the countries which are to become technological from those which suffer from an ever-increasing technological gap.

We must also consider that the degree of success in the transfer must depend largely on the kind of technology chosen. To find the conditions for successful transplantation, we shall examine several selected technologies of entirely different types, some purely imported and some autochthonous.

Early Efforts, 1868-1885

The Utilitarian Image of Science — It is a common belief among historians of Western science that in pre-modern times science and technology have been distinct activities with different social origins. In spite of the effort made by the Encyclopedists to liquidate this social interface, the dual structure of science and technology was still maintained, even in the nineteenth century, by socially separated groups. This was exemplified by such institutional separations as between the German Universität and the Technische Hochschule. However, there was no particular reason for the mid-nineteenth century Japanese to distinguish between science and technology when facing the impact of modern Western military aggression. To the Japanese it appeared that modern science and modern technology grew in a single Western tradition. It was not the science-versus-technology dichotomy but rather the tradition-versus-Western dichotomy over which the Japanese were seriously concerned.[48]

While science in nineteenth century Europe was still in the main a cultural activity, well illustrated by the issue of the theory of evolution, rather than a practical means of achieving economic growth, the Japanese image of science in the late nineteenth century was perhaps the most modern. It was exclusively utilitarian and pragmatic, planned for national interests if not purely for profit-making, specialized and compartmentalized. Emphasis was laid on physical and applied science rather than on biological, and hence the style was closest, for that period, to our contemporary scientific technology.

The Institutionalization of Science — Since the Meiji Restoration of 1868, the manner of the Japanese response to Western science was dramatically transformed. In the preceding Tokugawa period, Western science was initiated and advocated mainly by scholars in private sector. Only in the last period of Tokugawa rule were official training institutes for Western naval technology and related sciences opened in Nagasaki and elsewhere. Being hard-pressed by the urgent defence needs of the country, the administration could not develop enough foresight to build institutions giving fully modern and systematic education in science and technology. Under the new Meiji government, scientific education was completely institutionalized. Whereas formerly the study of Western science had had its origins in the private interest of the scholars or in immediate practical necessity, it now became firmly programmed in such a way that an institution was first created and then later European and American scientific and technical specialists were invited to meet selected native students within the institution and elite graduates were sent abroad for further study.[49]

Within the new government during its first two or three years (1868-1870), there was still an influential party who wanted a faithful restoration of the ancient imperial system of government, but the modernist leadership was soon established to follow the policy of westernization.

Guidelines for Westernization — In the draft rules for the dispatch of students for study abroad, prepared in 1870,[50] the following subjects and countries of study are listed :

CHOICE OF COUNTRIES TO STUDY

Britain	: Machinery, geology and mining, steel making, architecture, shipbuilding, cattle farming, commerce, poor-relief
France	: Zoology and botany, astronomy, mathematics, physics, chemistry, architecture, law, international relations, promotion of public welfare
Germany	: Physics, astronomy, geology and mineralogy, chemistry, zoology and botany, medicine, pharmacology, educational system, political science, economics
Holland	: Irrigation, architecture, shipbuilding, political science, economics, poor-relief
U.S.A.	: Industrial laws, agriculture, cattle farming, mining, communications, commercial law.

In view of the history of nineteenth century science, the above assessment was, by and large, correct and objective. Presumably, the policies for science and technology, including the above recommendation, were drafted mainly on the suggestion of G. F. Verbeck and other foreign advisers to the government.

Employment of Foreign Scientists and Engineers — From about 1870, a policy was adopted for the employment of Westerners from various countries to guide the teaching in schools and governmental enterprises. In the actual execution of the employment programme, the lines prescribed above were not exactly followed but there was, in fact, no great deviation from them.

French engineers were employed in the army, in mines and in dockyards; Germans were employed for medicine and basic sciences in the schools, while a number of Americans were employed as agricultural specialists for the Commission for the Colonization of Hokkaido, where American large-scale cultivation was tried out.

The British were most numerous in many fields; nearly a hundred were employed in the construction of railways. Generally, in the engineering field, the greatest contributions were made by the British. At the Imperial College of Engineering (Kobu daigakko) which existed from 1873 to 1886, the teaching staff was mostly British and was directed by a Scottish engineer, Henry Dyer.

The number of government employees reached its peak in 1874. The total of the employees' salaries also reached its peak in the same year, its ratio to the total national expenditure was about 2%. Apparently the government wanted to reduce the number and expenditure on foreign employees, who were paid salaries 10 times larger than the Japanese, and to replace them with natives who had received scientific training in the West. For this purpose, the Ministry of Education allocated funds, but the amount was still far less than the foreigners' salaries.

Students Sent Abroad for Study — In the matter of sending students abroad at the expense of the government, the programme was at first not well organized and in 1873 it was totally abolished. In 1875, in its place, the Ministry of Education (Monbusho) instituted overseas scholarships. The Ministry of Technology (Kobusho) followed suit in 1880. As they had already received basic training from foreign teachers at home, science students overseas spent more time in research and technology students in the observation of actual practice in business.[51] When they returned, professorial or corresponding posts were awaiting them in Japan. They constituted the first generation of Japanese professors at the University, displacing the foreign instructors.

Until about 1877, education in Japan put more stress on language study than on the study of one's special subject. There was, therefore, a tendency among the early students to choose the country, the language of which they had studied. After a political incident in 1881, however, the Japanese government started a definite policy of copying the German educational system and political institutions, and accordingly many students turned their attention to Germany, even in the fields of science and technology. It was the heyday of German science... students from England, France and America were going to Germany for advanced studies... and naturally the Japanese students must have been impressed by the German scientific leadership. Out of 26 Japanese Doctors of Science conferred by 1891, 13 had study and research experience in Germany, outnumbering 5 from America and 3 from Britain.[52]

Emphasis on Physical Science and Specialization — Japanese pioneers in Western science during the late Tokugawa period were impressed by the Western process of inquiry into physical laws, rather than by the aggregate of facts and objects of nature. They[53] came to feel keenly that, although there was no great gap between East and West as far as the classificatory knowledge of natural history was concerned, Chinese and Japanese cultures seriously lacked the belief in the underlying regularity in Nature and the "investigation of its principles", namely natural philosophy.[54] Along with this tradition of viewing Western science, the primary school curriculum, prescribed for the first time by the Ministry of Education, was not natural history and biology oriented, like that of American primary education, but physics oriented.[55]

During the 1870's and 1880's the relative position of science and technology in the whole Japanese educational curriculum, from elementary school to university level, was much higher than in any other nation. For instance, mathematics and science occupied about one-third of the school curriculum at the lower grades (first four years) and two-thirds at the upper grades of the eight-year elementary education, though due to the shortage of qualified teachers available it was somewhat questionable to what extent these ideal plans were put into practice. At the university level too, the emphasis of science and technology was evident in the high percentage of graduates in scientific disciplines of Tokyo University (85% in the 1880's as compared to 40% in the 1920's).

Official and Planned Character — At the frontiers of newly forming disciplines in nineteenth-century Europe, the scientist was free to take up for his research any problem that interested him, and the scientific communities were formed by individual scientists drawn together by a common interest. At the research front the voluntary activities of scientific or professional societies usually preceded their inclusion in the university curriculum. In the case of Meiji Japan, and generally in the case of the artificial transplantation of a foreign discipline under state sponsorship, this process was reversed. The government first created institutions for training scientific personnel and only then did university graduates in each discipline form their scientific societies, not purely for academic purposes, but mainly with common interests in their new and still very weak scientific careers. Created in this way, the scientific community in Japan had a "planned character", planned by and for the set purpose of catching up with the Western standard of science as quickly as possible.

In the nineteenth century, however, it was uncommon, even among the advanced nations to find established precedents or formulas for a national science policy. Thus, the Meiji government had to find its own way by trial and error.

On the practical level, first of all, it urgently needed qualified teachers and engineers in building up a modern state. Here the new government, in pursuit of its set aim, built schools and factories, trained scientists and engineers in these temporary institutions, and sent them off to their posts. Rather than having every scientist following his own research interest, priority was given in a collective way to certain basic tasks, the accomplishment of which was necessary for the operation of a modern state: matters such as geographical and geological surveys, weights and measures, meteorological observation, sanitation, printing, telegraph and telephone, military works, railways, survey of natural resources, etc. All these activities were carried out by the Ministry of Technology, the Ministry of Interior, the Ministry of Finance, the Commission for the Colonization of Hokkaido, the Army, the Navy and other functioning governmental agencies under the supervision of many foreign engineers working in Japan. To conduct such big nation-wide projects, these agencies had to have their own short-course training programmes to provide field assistants to foreign employees. These agencies did not then exclusively depend on the Ministry of Education, which was responsible for regular long-term educational programmes. An example was the Telegraph School of the Ministry of Technology.

We may label these activities as "public science" initiated by the government. This step in science for public service was the indispensable prerequisite for the industrialization by the next generation.

Besides this, the government entered into private entrepreneurship, constructed and managed pilot plants and guided and subsidized new kinds of industries. The Ministry of Technology and the Commission for the Colonization of Hokkaido were the two major institutional innovations, which carried out new experimental programmes and were also, the centres of westernization and modernization.

Their enterprises were from the beginning exposed to financial risk. Many of the projects of the Ministry of Technology eventually proved to be too far ahead of their times, as they intended to introduce the technology of an industrialized society into a pre-industrial environment. For instance, their railway construction enterprise was economically unsuccessful at the time, and only paid-off commercially after 1885 in the next phase of industrialization.

Thus, Y. Fukuzawa, Japan's foremost exponent of industrial revolution, concluded that "we should not blame them too much for their financial failure. After all, it was a costly tuition fee for the Japanese to learn civilization".[50]

Lack of Research — This planned character of the Japanese science has one notable defect. The institutionalization of science and technology with the governmental initiative was certainly a very efficient tool for transplanting and inducing foreign science and technology, but it was not so good for the purpose of fostering original creative activity. Institutions were divided from the outset into specialized disciplines, each scientist and engineer assuming his specialized role.

In fact, in comparison with the traditional Confucian learning, the Japanese in the early Meiji period found the strongest point of Western science to be its specialization. This was a particular late nineteenth century aspect of science, not found earlier. The term coined by the Japanese in the 1880's as a translation of the word science was *kagaku,* which originally meant study of one of the hundred departments and was the equivalent of the German term *Fachwissenschaft.*

Thus, each scientist or engineer was concerned with absorbing the foremost achievements of the western world, each within a narrowly prescribed disciplinary barrier, rather than cooperating with his Japanese colleagues in different fields.

The other side of science policy, namely research policy, was tactfully avoided. Research policy in any systematic form was the product of the war mobilization of science during the World War I, and hence it is not at all unusual that the Meiji government paid practically no attention to scientific research. However one thing should be noted. Unlike other European monarchies, the Japanese had no great interest in founding a national academy of science as an ornament or a status symbol for an independent state. To the practically oriented Japanese, pure research was totally subordinated to manpower policy and thus the Tokyo University had enjoyed the position of top educational institution as well as the highest academic prestige in the country.[57]

For the first generation of scientists in the early Meiji period it was more important to build up institutions than to pursue piecemeal individual research topics. Exceptionally; there could be found some internationally notable contributions made by early Japanese scientists, such as S. Kitasato's works on microbiology, but these usually originated during research apprenticeship in the West. At home, research workers could not find any colleagues for discussion, unless they trained their own students in the same research tradition. Thus, they became exclusively involved in administration and education, eventually forgetting their days of activity at the research front in Europe.

At home, there was much to be done on local subjects. What they did was mainly local science, namely, the application of modern scientific methods to the analysis of local matters and affairs, such as flora and fauna, earthquake and geological observations. Such disciplines as zoology, botany and geology remained local sciences, at least until the World War II. Even in such methodically oriented disciplines as physics and chemistry, the early scientists' concern were for geophysical observations and the chemical analysis of local products. Up to 1885, more than half of the research articles published by the faculty members of College of Science, Tokyo University, were on local science.[58]

The Samurai Spirit in Science and Technology — Modern scientific and technological professions were the artificial creation of the new Western-oriented government. The main practitioners of these new professions were former samurai, who were warriers by definition but during the Tokugawa period became primarily administrative bureaucrats. In the past they had received hereditary family stipends in exchange for their loyalty to the feudal powers, the Shogunate or local feudatories. They were the class long accustomed by mental habit to think in terms of public affairs and by behaviour pattern to playing the game of public offices.

Hence, Japanese modern science and technology professions were, in the beginning of their formation, very much "samurai-spirited". Unlike European pattern in which science and technology was one experience of the rising bourgeois, middle class Japanese scientific and technological professions in the last quarter of the nineteenth century were dominated by the proud old samurai class, comprising the top five per cent of total population.

In the 1870's, efforts were made by the Meiji government to curtail the inherited family stipends of the samurai class as a preparation for modernization. While other classes, farmers, artisans and merchants, could continue to be engaged in their inherited vocations, samurai completely lost their vested source of revenue. Consequently, the samurai had to find new ways of living independently. Modern efficient government needed as personnel less than ten per cent of the whole samurai population, and hence the rest were forced to find an entirely new means of living elsewhere. Since samurai could not compete with other classes in the fields of traditional business, they were invited to engage in the new business projects like agricultural exploitation of Hokkaido, silk manufacturing and textile industries, etc. This was especially the case after 1876 when the former privileges of the samurai were finally extinguished.

Science and technology was one of these new fields into which jobless samurai were attracted and invited. It was reported that almost all of the early graduates of the engineering college were samurai.[59]

Even as late as in 1890, the percentage of samurai graduates in each school of the Imperial University is as follows[60]:

PERCENTAGE OF SAMURAI GRADUATES IN IMPERIAL UNIVERSITY (1890)

Engineering	majors :	85.7
Science	,, :	80.0
Literature	,, :	75.0
Law	,, :	68.3
Agriculture	,, :	55.9
Medicine	,, :	40.8

We find here a conspicuous difference between the science and technology group with the highest rate of samurai origin and medico-agricultural group with the lowest.

In interpreting this difference, we may assume that those graduates from medical and agricultural schools were respectively mostly sons of former medical practitioners and farmers, whereas many samurai, deprived of status and occupation, found their most promising career possibilities in the entirely new professions of science teaching and engineering. Science graduates as the teachers and promoters of the new Westernization policy, and technology graduates as technocrats in building up a modern state, satisfied the former samurai's aptitude for administrative posts, their accustomed class vocation, as science and technology were, at least in the early Meiji period, purely governmental enterprises of top priority.

Apart from ideological issue, and perhaps more important, the sons of the impoverished samurai class, whose future was insecure, were attracted to government-sponsored careers in science and technology, where tuition was free, grants were provided and future government posts were obligatory on graduation.[61] Thus, science and technology provided new horizons for such careerists.

Reorganization and Take-off, 1886-1914

Reorganization of Institutions Around 1886 — After two decades of intensive cultivation programmes, including the institutionalization of science and technology, Japan was now prepared to take-off and become a modern industrial state. Around 1886, the early efforts of the Meiji government reached a turning point, at which many of the early enlightened policies were re-assessed, re-formulated and re-organized.

The most significant and symbolic event was the dissolution of the Ministry of Technology in 1885. Many governmental enterprises were transferred to the private sector, mainly because the government as well as outside critics realized the inefficiency of government factories in profit-making industrial activities. Public-minded samurai engineers accordingly moved into the private sector.

By 1886, when the Tokyo University was re-organized into the Imperial University by uniting the Imperial College of Engineering with the Ministry of Technology, foreign teaching staffs were mostly replaced by native scientists who had just returned home from studying abroad, and thus the propagation of scientists and engineers became possible.

Until 1885, the scientific public services, such as surveying, had been conducted by transitional manpower who had an intensive short-course instruction and had training mainly on the job. After such services were set up in outline, many transitional schools and transitional offices were then closed and around the time of the founding of the Imperial University in 1886, the vocational engineering schools[62] were re-arranged more systematically to provide second class engineers for Japanese industry which was at that time maturing to the extent that it badly needed low and middle class engineering manpower. There were placed hierarchically with the Imperial University at the top.

The days of enthusiasm for Western scientific civilization were then over, and the government became more interested in having good quality administrative bureaucrats, rather than entrepreneurial technologists, for the maintenance of regime being steadily established. In public sector, law school graduates of the Imperial University received governmental favour and engineers were placed in positions subordinate to them.

Language Problem — In the early days of Meiji period, college teaching was still conducted, even by native Japanese teachers, in foreign languages, such as English, German and French, according to the country where they were trained. It was gradually replaced by the native tongue by 1900, though technical terms remained untranslated.

It was once seriously proposed by A. Mori, a thorough exponent of modernization and westernization, that the Japanese language should be wholly replaced by English, in order to follow the international standard of knowledge as closely as possible, but his plan was never put into practice. If it had actually been enforced, it might have created dual culture with an English speaking high-brow upper class, and it would have blocked or considerably delayed the diffusion of Western scientific culture among the populace who would continue to speak Japanese.

In the nineteenth century scientific community, English was not so predominant a language as it is now. In the Imperial University, while English prevailed in the School of Engineering, the Medical school adopted German as its academic language as early as in 1869, and this tradition lasted until some time after World War II. Further, German was the second language taught at higher school level next only to English. Because in the late nineteenth century Germany was leading the world of science, Japanese students were required to learn it as a scientific language.

The Dual Structure of Japanese Technology — Modern engineering and technology may be said to have two entirely different origins. One is the "community-centered" or "public-centered" engineering service practised in the public sector, best exemplified by the discipline of military engineering taught and practised in the celebrated French Ecole Polytechnique, and the other is "self-centered", profit-making capitalistic engineering practised in the private sector, as exemplified by the Watt-Boulton type of enterprises, power engineering, pharmaceutical technology and so on.

The traditional Western dichotomy created in the Japanese technological world could be translated in socio-economic terms into the private-public dichotomy. Private technology is not only "self-centered" and profit-making, but also traditional and domestic, not based on science, and transmitted through apprenticeship in the non-samurai sector, such as in *sake* brewing and in ceramics. Public science and technology are, on the other hand, not only "community-centered" but of Western origin, university-based and hence science-based, and practised mainly by the samurai class elite.

Traditional craftsmanship, such as carpentry and fishery, remained outside the governmental enterprise for building up a system of modern science and technology in the country. Established scientific and technological professionals worked in complete separation from traditional craftsmanship, finding appropriate niches in various governmental works, such as the office of the geological survey and in military arsenals.

In what follows we will examine the actual state of this dual structure using the list of patent applications.

In 1885, the Patent Law was issued and one hundred patents were granted in the first year of its enforcement. This was to protect the honour and profits of native Japanese inventors against other Japanese and had no international implications.

In the early Meiji period, Western industrial designs and inventions were not legally protected in Japan and the Japanese were free to appropriate them. From the Western point of view, it was claimed that Japan should subscribe to the international patent regulations, as otherwise the Westerners would not be willing to give freely their technological advice without the fear of unlicensed Japanese copying. But, those who welcomed the enforcement of international regulations were, of course, the Westerners rather than the Japanese. Around 1885, a big political and diplomatic issue in negotiation with major Western powers was the adjustment of unequal treaties. The government intended to give patents to foreigners in exchange for Western denouncement of unequal treaty items,[63] and formulated domestic patent system in preliminary form with the intention of later stepping further into international affairs. The treaty amendment was postponed to 1899, when Japan subscribed to the International Industrial Property Regulations and only after that foreigners obtained Japanese patents at a rapidly increasing rate.

Out of the first one hundred patents issued in 1885, applications by former samurai are only 17%.[64] This is in clear contrast with the fact that samurai made up a high percentage of the College of Engineering graduates of the Imperial University in 1890. If we look more closely, we find that many of the 17% samurai applicants signed only as investors rather than as inventors.

This contrast may well be explained by supposing that while elite graduate engineers were busy introducing and translating the high technology imported from the West, inventive skill in the private sector was being demonstrated in local technological adaptation.[65] College graduates were engaged in public works of non-self-centered kind and thus it was perhaps not proper for them to apply for profit-making patent rights whereas private sector inventors were eager to get the honour of official recognition, even if the invention was not put into profit-making practice. Only in the twentieth century, after Japan had subscribed to the International Industrial Property Regulations in 1899, were high-level engineers concerned with patent rights.

Since 1899, Japan received a number of foreign applications for patent protection. It is interesting to note what countries were most interested in obtaining Japanese patents. Looking at the kind of patents, it can be noticed that the USA was particularly strong in the field of newly invented electrical equipment and Germany was strong in weapon manufacturing and chemicals. British interests were all-round but particularly strong in shipbuilding.

Rise of Technocrats — World War I and After

Start of Financing Scientific Research—Up to the 1880's, the scientific institutions created by the government were mostly of the geophysical kind for survey work as listed below:

Navy Hydrographic Office (founded in 1871)
Tokyo Meteorological Observatory (1875)
Geological Survey (1882)
Army Ordnance Survey (1884)
Tokyo Astronomical Observatory (1888)

Their work was essential necessities for operating a non-industrial modern state. Since the 1890's, however, many national research institutes were established for fostering industrial development, such as the following:

Electrical Laboratory (created in 1891)
Central Inspection Institute for Weights and Measures (1903)
Fermentation Laboratory (1903)
Railway Research Institute (1907)

and so on. Before the coming of World War I, Japanese industrial laboratories were created only in the public sector in order to give guidance in the technology needed by private enterprises.

The war mobilization of research in Europe and the USA during the World War I gave great stimulus and opportunity for government and scientists in Japan to think about the financing of scientific research. Taking advantage of the war-time economic boom, particularly fortunate for the Japanese, who stayed out of major hostilities, many proposals from technocratic and scientific spokesmen invited the attention of public and industrial establishments. This was the time when scientists changed from the old-fashioned generation of academic bureaucrats to the new technocratically oriented, who advocated planning of scientific research for national goals.[66] The latter generation was backed by the newly rising industrialists in business sector. The creation of the *Riken*[67] (Institute for Physical and Chemical Researches) in 1917 was a landmark in this change-over, since the major source of funds was the industrial sector (85%) rather than the government. During and after World War I, various private enterprises, notably in the innovatory chemical industry, established their own full-scale industrial laboratories for the first time. This signified the maturity of capital formation as well as the rise of interest in R & D in the private sector.

It was also during World War I when other unique arrangements to promote scientific research started in the public sector. These were the creation of university-affiliated research institutes and of governmental research funds.

Owing to increasingly high specialization and the advancement of research front in science and technology, the old Humboldt idea of the unity between education and research at university level was virtually broken down in the early part of the twentieth century. The American solution of the problem was to create graduate schools, so that unity was delayed from undergraduate to graduate level, where matured research students could be educated by formal curriculum as well as by apprenticeship at the research front. The other solution was the German way of creating a governmental research institute, called Kaiser Wilhelm Gesellschaft, to liberate scientists from their educational burden and this model was rather faithfully followed by the Soviet Academy of Science.[68]

The Japanese tried to get rid of this difficulty by creating the *Riken*, modelled after the Kaiser Wilhelm Gesellschaft. Still more significant was the affiliation of research institutes to a governmental university, where professors were full-time researchers without formal obligations to teach, but enjoying academic freedom and higher standing than those at the governmental and industrial laboratories.

The Ministry of Agriculture and Commerce created an Invention Fund in 1917 to encourage inventive researches and later also an Industrial Research Fund. The Ministry of Education Science Research Grant Programme was started in 1918. Various other small philanthropic foundations were also created during the War for the promotion of scientific research. This heyday of scientific research funding was rather short-lived, as the economic recession started in 1920 and the amount of government funds were either decreased or stayed level.

The worldwide depression of 1929 had relatively little influence on Japanese business, because Japan's involvement in the Manchurian Incident of 1931 caused a munitious boom. A study of the industrial production indices of Japan and the USA shows that while up to the start of Word War II the USA was unable to recover its 1920 level of prosperity, Japan soon regained normality.

This new development was centered mainly in the heavy industries. By about 1935, heavy and chemical industry production exceeded that of light industry.

With the aim of avoiding economic depression by means of scientific research and of promoting internationally the competitive power of industry, the Japan Foundation for the Promotion of Science was created in 1931. It arose from a proposal by scientists and started functioning in 1933 with governmental funds dramatically bigger (about ten times) than any ever contemplated before. Nationalization of science was world-wide trend at this time, but Japanese science took particular advantage of this trend to reach international standards.

In spite of heavy governmental intervention in scientific research, we should not overlook the trend, constant since the early Meiji period, towards moving industrial technology from the public sector to the private sector, as reflected in labour shift from public to private sector in machinery industry. As 1930 survey indicates, nearly half of researchers in engineering fields work for private business.

We are all concerned with finding an indicator for the military inclination of pre-war Japanese scientific research, but in the absence of adequate data, we must temporarily be content with Hiroshige's rough estimate that in 1931 nearly half of the national research investment in engineering field went to military research establishments.[69]

Thus, we may characterize the inter-war period as involvement in world-wide nationalization and militarization of scientific research superimposed on the background trend of the constant transfer of industry from public to private sector.

World War II and After

Leadership Moving to the Industrial Sector — Since 1939, the profound war-time recognition of the need for science mobilization and armaments led to the expansion of educational programmes for high class scientists and engineers (in one estimate three times the usual scientific manpower were produced). As the war intensified, students of the humanities were called to the front, while students of science and technology were exempted from front-line service.

Particularly favoured during the war-time was engineering research, because of demands from the military as well as from the business world. According to a questionnaire sent to engineering scientists after the War, their happiest time was that of the War mobilization, when they were given preferential treatment with abundant expenses and materials. Furthermore, the complete isolation from Western scientific circles inevitably provided an opportunity for public recognition of those who had formerly been psychologically dependent on the Western authority in each field.

Right after the War, many Japanese spokesmen of science criticised the lack of recognition in pre-war Japanese society of the importance of scientific research, which had contributed to defeat. The experience of military supremacy, thought control and the virtual failure of War mobilization must have given many scientists bitter memories and led to a negative assessment of war-time efforts. War-time seclusion specially resulted in a hiatus which faced the post-war generation with tremendous difficulties. It is only recently that more critical attempts to re-evaluate war-time scientific efforts as the source of the post-war boom in Japanese technological advancement and economic growth have appeared.[70]

During the occupation years, some strategic research, such as atomic and aeroplane researches were forbidden — the two Japanese cyclotrons were thrown into the sea — by Occupation forces. Demilitarization and the demobilization policy cut most of the governmental support of science and this may be partially responsible for the post-war transfer of scientific and technological leadership to the private sector.

In every advanced country after the War, government had supplied the largest share of funds for scientific research. In contrast to this, in post-war Japan private enterprise, which formerly did not account for any large sum of research funds, came to occupy a significant position in scientific research.

Military research is almost totally absent, and Japanese private enterprise has grown to the point where it needs and is able to sustain its own independent research. Against a universal trend in the post-war period to move towards "government science" or "nationally sponsored science" like the big schemes of space and atomic researches, the centre of gravity of Japanese science took a definite step from the pre-war public to the post-war private sector.

The pre-war public spending for defence and industry is now turned to social welfare, development and education. This trend is reflected in the structure of scientific and technological research in such a way that post-war Japan is said to have wisely stayed out of big science, defence or non-defence, in the public sector to have concentrated on profit-making, economical development on the basis of imported know-how. However, Japan is now facing the problem of a laissez-faire science policy, which may be partly responsible for heavy pollution and other public nuisances. At the same time, when the source of technological borrowing is nearly exhausted, Japan may have to find new, costly ways of breaking-through by itself. The Japanese government is beginning to take note of this reality and the national budget for scientific research is being increased gradually and steadily.

Conclusion

Looking back at the past of Japan's science and technology, which started out in the early Meiji years under government sponsorship, the direction of the scientific information flow has been always one-way, from abroad to the public sector, and in turn, from public sector to private sector. In this channel of introduction, the public sector has always played the role of turning Japanese science and technology towards the directions which are their own most serious concern, i.e. enriching and strengthening the country.

The course of endeavour was first determined by the samurai intellectual class, which was looking for an entirely new kind of job when deprived of family stipends. They took the initiative and were wholly responsible for the systematic introduction of technology in public institutions. The process of modernization could, however, never be successfully completed unless the efforts in the public sector reached the private sector. Early enthusiasm for Western science led to the diffusion of the ideology of modernization to the social grass-roots. At the same time this educational effort resulted in the liquidation of samurai-commoner class difference to the extent that by the 1920's commoners had a higher representation among the students of the Imperial University.

Merely as a device for explaining the transfer process, we introduce the following matrix :

	Western-origin	Tradition-bound
Public	I (military)	II (mining)
Private	III (matches, textiles)	IV (agriculture, brewage)

Technology of Western-origin was usually practised in the public sector and tradition-bound technology n the private sector. In the process of the transfer from Section I, there are some adaptive technologies which emerge in Sections II and III. We will examine the success or failure of technology transfer from the imported Section I to other sections.

In the early Meiji period, college graduates, mostly of samurai origin, were busy in reading and translating Western scientific works, visiting and studying in the West, learning Western science, copying high technology and assisting Western advisers, teachers and engineers in surveying and construction jobs, and finally in planning for Japan to become an industrial nation, catching up with the most advanced high technology (Section I). On the other hand, more practical inventions and improvements at the grass-roots level were made by non-samurai, artisans and experienced veteran farmers in the tradition of domestic industries, often awakened by stimuli resulting from westernization policy (Section IV).

Governmental enterprises focused their effort on those works where no existing system was available, like railway construction and telecommunication (I to III) or where large scale capital and mechanization were needed, such as government-owned mines (I to II). In such fields, all essential aspects of enterprises were introduced *in toto*; not only chief engineers but even lower class workers were recruited from abroad. Production technology and the production system were radically different from the domestic ones; even where traditional domestic engineering and industry existed in such fields as shipbuilding and spinning industry, the mechanization system as well as the managerial form was imported as a single inseparable unit.

It is certainly true in Japanese's past experience that a special adaptive technology was selected in order to compete with more capital-intensive advanced countries by using her cheap labour. This aspect was not consciously emphasized by the Meiji government, whose foreign advisers, with very few exceptions, lacked much imagination in adapting Western technology to local situations. Their samurai followers, without much job experience in domestic technology, tried to copy and demonstrate the Western technology often with disastrous results, as they invited the abolition of the Ministry of Technology, the strong hold of westernization and modernization. A notable labour policy of the Meiji government was to provide jobless samurai with new means of livelihood, but in so doing the government did not seem to have conceived of labour-intensive intermediate technology, but rather directed them into more labour-saving new technologies, such as large-scale farming in the Colonization of Hokkaido and in mechanized mining.

On the other hand, in purely domestic industries in the private sector where no similar Western counterpart existed, in such fields as rice paddy agriculture, *sake* brewing and lacquerware and ceramic production, the innovation process was naturally very slow and gradual. Only the generation which had been trained with the modern Western style school curriculum in science and technology, began to utilize the knowledge acquired at school and apply it, if practicable, in their inherited domestic businesses.

In between the two above-mentioned extremes, there were many intermediate technologies. There were cases in which the production scale was too small to be a governmental enterprise, but still local demands made the private sector quite receptive to the imported new knowledge. The typical one must be the match manufacturing industry, where at first cheap labour and splints were the only exploitable factors, but later potassium chlorite and phosphorus were made domestically to complete all processes in Japan. Silk reeling and textile manufacture were also such that imported machinery in government pilot plants was a model to demonstrate the technological way forward but in reality production was carried out for a considerable period by the use of home-made wooden machines and small-scale production systems. The local synthesis of the two extremes was often found in this area of the transfer section.

Finally, the most important technology should not be forgotten; that is, arms technology. It remained all the time within the public sector. The major parts of mechanical engineering and naval architecture were monopolized by military arsenals and big governmental industries without much effect on the private sector. Machine tool engineering was, despite its basic character, relatively neglected and continued in small-scale private business.

If we characterize one hundred years of Japanese industrial development by one phrase, it was a constant process of transfer from the public to the private sector. This transfer policy was publicly announced and was followed in practice during the 1880's. This process was basically, if not explicitly, continuous, although often interrupted by the effects of the governmental armaments industry.

This effect totally disappeared after World War II. Now, with economically motivated private industry based on profit-making, a laissez-faire kind of science and technology became dominant in the budgeting structure of post-war Japanese research and development. This contrasted with other advanced nations, such as the USA and Britain, where public expenditure for science and technology became the major and predominant source of research budgets.

Post-war Japan also presents an embarrassing example which conflicts with the prevailing belief that science and technology input contributes to economic growth in proportion to its size, i.e. among advanced nations Japan paid less for science and technology and gained more in economic growth. Unless we specify the quality of science and technology and the quality of economic growth, we may not be able to say anything definite, but the post-war private leadership in Japanese industry and technology may give a clue to this open question.

On the level of catching up and profit-making, post-war Japan proved that borrowing is less expensive than spending on costly original research. In so doing, she needed more intermediate scientific manpower rather than highly talented Nobel laureates. This could be done only through a social turn-over in which vertical as well as horizontal mobilities should be accelerated for the recruitment of scientific and technological manpower.

Let me conclude with a metaphor. Science and technology have been usually received in the upper strata of a society in the developing countries, and then has penetrated into the society as a whole. These two steps were taken in an unusually orderly fashion in the Japanese case. If a class system is too tight to dissolve, the ferment fails to reach the lower level.

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17. Manfred Porkert, *Theoretical Foundations of Chinese Medicine* (MIT Press), 1974.
18. Tsuruoki Genitsu, *Idan* (Medical Critique, 1795).
19. *Dictionary of Scientific Biography*.

20. Ogawa, "Meiji zen Nihon kaibo gakushi", p. 92 ff. and Uchiyama Koichi, "Nihon seiri gakushi" (History of Physiology in Japan) *Meiji zen Nihon Igakushi*, Vol. II, p. 122 ff.

21. *Yakucho* (Pharmacological Effects) Vol. II, reprinted in *Nihon shiso taikei, kinsei kagaku shiso, ge* (Modern Scientific Thoughts), Vol. II, p. 256. See also Otsuka Keisetsu, "Kinsei zenki no igaku" (Medicine in the Early Tokugawa Period) in the same volume.

22. Shigeru Nakayama. "Kindai kagaku to yogaku" (Modern Science and the Western Learning) in *Yogaku ge*, pp. 460-461.

23. "Scientific Productivity and Academic Organization in Nineteenth Century Medicine", in Bernard Barber and Walter Hirsch (eds.), *The sociology of science* (The Free Press of Glencoe), 1962. pp. 305-343.

24. For instance, Mikami Yoshio, *Bunkashijo yori mitaru Nihon no sugaku* (Japanese Mathematics from the Viewpoint of Cultural History, Tokyo), 1947 and Ogura Kinn suke, *Nihon no sugaku* (Japanese Mathematics; Iwanami), 1940.

25. Hirayama Akira, *Seki Takakazu* (Koseisha), 1959, pp. 178-179.

26. For instance, *Daijutsu bengi* (Discussions on Problems and Solutions).

27. Nathan Sivin, "Cosmos and Computation in Early Chinese Mathematical Astronomy", *T'oung Pao*, 1966, Vol. 55, pp. 1-73.

28. *Hsin T'ang Shu* (Dynastic History of T'ang, Newly edited), Calendrical chapter; Yabuuchi Kiyoshi, *Zuito rekihoshi no kenkyu* (Researches in the History of Calendrical Science during the Sui and T'ang Periods, Tokyo), 1944.

29. Okumura Tsuneo, "Kinsei shonin no sanyo ishiki" (Mathematical Concern of Modern Merchants), *Shuzankai*, 1969 (September), p. 5.

30. Murai Masahiro, *Ryochi shinan, kohen* (Introduction to Surveying), Vol. 2, 1754, preface.

31. *Ibid.*, p. 4.

32. Kasai Sukeharu, *Kinsei hanko niokeru gakuto gakuha no kenkyu* (Researches on Academic Tradition and Schools in Modern Fief Schools), Vol. 1 (Yoshikawa Kobunkan), 1969, pp. 9, 75.

33. Hirayama Akira, "Wasanka no shokugyo" (Occupations of Japanese Traditional Mathematicians) in *Kyodo sugaku no bunkenshu*, No. 1.

34. Mikami Yoshio, "Sugakushijo yori mitaru nihonjin no dokuso noryoku" (Japanese Creativity on the History of Mathematics), *Wasan kenkyu*, No. 11, pp. 7-8 (October 1961, originally written in 1927).

35. Mikami Yoshio, "Yureki sanka no jiseki" (Facts about Wandering Mathematicians) in *Kyodo sugaku no bunkenshu*, No. 1.

36. Thomas Kuhn, *Structure of Scientific Revolutions*, (Chicago), 1962.

37. Hosoi So, *Wasan shiso no tokushitsu* (Characteristics of Mathematical Thoughts in the Wasan Tradition, Kyoritsu), 1941, p. 44.

38. Puzzle-solving is the most basic of scientific activities.

39. For instance, Ogura Kinnosuke, *Nihon no sugaku* (Japanese Mathematics).

40. Ajima Naonobu, *Seiyo sanpo* (1779), postscript.

41. Hosoi, *Wasan shiso,* pp. 48-49.

42. Fujiwara Matsusaburo, *Nihon sugakushi yo* (Epitome of Japanese Mathematics, Hobunkan), 1952, p. 127.

43. Hosoi, *Wasan shiso,* pp. 69-78.

44. *Ibid.,* pp. 298-300.

45. Takebe Katahiro, "Tetsujutsu" (1722) in Saegusa Hiroto (ed.), *Nihon tetsugaku zensho,* Vol. 8 (Daiichi shobo), 1936, p. 375.

46. Joseph Needham, Shigeru Nakayama, "Chugoku no kagakushi O megutte" (On the History of Chinese Science), *Gekkan Economist,* 1974 (October), pp. 86-87.

47. Joseph Needham, "The Historian of Science as Ecumenical Man", S. Nakayama and N. Sivin (eds.), *Chinese Science,* (MIT Press), 1973.

48. Until the 1880's, the Japanese language did not distinguish clearly between 'science' and 'technology'. The separation between the concepts became real only towards the close of the century when autonomous scientific communities were formed at the university faculty level.

49. S. Nakayama, "Kokuei kagaku" (Nationalized Science) in I. Sugimoto (ed.), *Kagakushi* (History of Sciences), Yamakawa, Tokyo, 1967, p. 351 ff.

50. The original is reprinted in S. Nakayama *et al.* (ed.), *Nihon Kagaku gijutsushi taikei* (hereafter abbreviated as *NKGT*) (Source Books of the History of Science and Technology in Japan); international relations (Daiichi-hokii, Tokyo), 1968, pp. 35-36.

51. *NKGT*: *Kyoiku I* (Education No. 1), 1964, p. 353.

52. *Ibid.,* pp. 392-393.

53. An intellectual tradition started from B. Miura and T. Shizuki through Y. Fukuzawa.

54. They have appropriated Neo-Confucian concept of *kyuri* for the translation word of natural philosophy (in Dutch *natuurkunde*) but later especially in the Meiji period, this term was specified to mean physics.

55. *NKGT* : *Kyoiku I,* p. 202.

56. *NKGT*: *Tsushi I,* pp. 180-186.

57. The Japan Academy was founded as early as 1879, but it was a gathering of outdated scholars of general Western learning and was often ridiculed as being a home for the retired.

58. *Tokyo Teikoku Daigaku gakujutsu taiken, Rigakubu* (Survey of Research Activities in the Tokyo Imperial University, Faculty of Science, 1942). In chemistry department, the change-over from local science to the internationally appreciable subjects is notably sharp during 1885.

59. T. Muramatsu, "Nihon no kogaku soseiki no jakkan no mondaiten" (Some Problems of the Early Japanese Engineers), *Kagakushi Kenkyu,* 1954, pp. 8-14.

60. I. Amano "Kindai nihon ni okeru koto kyoiku to shakai ido" (Higher Education and Social Mobility in Modern Japan), *Kyoiku shakaigaku kenkyu,* 1969. No. 24; p. 84.

61. For the graduates of the Imperial College of Technology seven years' service in governmental factories was required.

62. Major examples are as follows : Ashikaga Textile Training Center founded in 1885; Kyoritsu Women Vocational Training School, Tokyo; Apprenticeship School of Commerce and Technology, Kyoto; Dyeing Training Center founded in 1886; Hichioji Textile and Dyeing Center; and Kanazawa Engineering School founded in 1887.

63. *Takahashi Korekiyo Jiden* (Autobiography of Takahashi Korekiyo, Founder President of Japanese Patent Office), the relevant part to the context is reprinted in *NKGT* : *Tsushi I*, p. 339-340.

64. "Tokyo dial-100 go no meisho oyobi shutsugannin ichiran" (Titles and Applicant's Names of Patent No. 1 to No. 100) in *Ibid.*, pp. 334-336.

65. A collected biography of Japanese investors in 1935 shows that college graduates comprise only 7%.

66. Hiroshige Tetsu, *Kagaku no shakaishi* (Social History of Science), (Chuokoron, Tokyo), 1973, chapter 3.

67. K. Itakura & E. Yagi, "The Japanese Research System and the Establishment of the Institute of Physical and Chemical Research" in S. Nakayama *et al.* (ed.), *Science and society in Modern Japan* (MIT & Tokyo Univ. Press), 1974. p. 158 ff.

68. Loren Graham, "The Formation of Soviet Research Institute : A Combination of Revolutionary Innovation and International Borrowing", XIVth International Congress of the History of Science, Proceedings, (Tokyo), 1974, No. 1.

69. Hiroshige, *loc. cit.*, p. 116.

70. *Ibid.*, pp. 216-220.