Japanese Modernization Lecture Series

Chapter 14. The Road to a Nation of Science and Technology

Contents

Introduction

Hello, everyone. I am Hasegawa Mariko from the Graduate University for Advanced Studies.

In this program, I would like to discuss how natural science is related to the modernization and development of Japan.

Japan is a small island nation in Northeast Asia, and for a considerable part of its fairly long history did not have a close relationship with Western European societies, where the foundations of today's science were laid.

Japan even closed its borders to the outside world during the Edo period (1603-1868).

We will explore how such a country adopted Western European and American science and developed these for its own benefit.

As of 2021, the number of Japanese Nobel laureates in scientific disciplines is 25, indicating that the country has considerable strength in this area.

Science and technology are two of the key elements in the modernization of a country.

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Let us consider how Japan aimed to become a nation of science and technology, and how it was capable of doing so.

Section 1: What is Science and Technology

In his 2011 book *Civilization: The West and the Rest* (Penguin), the Scottish historian Niall Ferguson listed six factors that contributed to the West's dominance in the world in the early modern period.

One of these factors was the creation of modern science.

I certainly agree with him.

So, let us think about what made science such a powerful force in civilization.

What is Science?

Science is an activity based on our desire to know why things are the way they are and to explain them.

People in any age and in any region have had such curiosity, and they have had ‘narratives’ to explain various phenomena in the world.

The science that we have today is one such ‘narrative’, except that it is unique in the way it was built, and it became very successful and spread all over the world.

No other narrative could have become such a universal one.

What is Technology?

What is technology?
It is the collection of tools that enable us to perform various tasks with more efficiency and accuracy.

It is also an activity based on the fundamental human desire to control the natural environment, and people everywhere have and use technology.

However, the invention of new technologies has often been carried out through individual processes of trial and error, rather than in accordance with any theoretical understanding.

Thus, the origins of science and technology as human activities are quite different.

The establishment of modern science in Western Europe

It was in the 17th century in Western Europe that ‘modern science’, the origin of today’s science, began.

Prior to this Western European society was Christian, and it was common sense to explain the natural and social environment based on the worldview of the Bible.

However, during the Renaissance, which began around the 14th century, it became mainstream not to interpret nature exclusively from what was written in the Bible, but to also observe nature with one’s own eyes and candidly describe its real mechanisms.

Later, Galileo Galilei (1564-1642), an Italian scholar who was active from the mid-16th to mid-17th century, started practicing a method of not only observing but also formulating hypotheses and conducting experiments to prove those hypotheses about the natural world.

Galileo improved the telescope and discovered, for example, that there were many craters on the moon and that Jupiter had four moons.

He also conducted modern style experiments, such as dropping balls of various weights from the Leaning Tower of Pisa and showing that they all reached the ground at the same speed.

This allowed him to mathematically demonstrate a law of physics relating to falling objects.

I just mentioned the telescope, which was a tool created out of the desire to see further into the world than human eyesight can.

To explain the world based on actual observations and measurements of nature as Galileo did, we need tools to observe and measure that world.

Therefore, technology like the telescope came to play an important role in the development of science, and a close relationship formed between them.

The method of observing with one's own eyes and confirming by experimentation, which emerged after the Renaissance, gradually spread.

The English philosopher Francis Bacon (1561-1626) and the French philosopher René Descartes (1596-1650) greatly contributed to the establishment of the foundations of modern scientific method.

Isaac Newton (1643-1727), who proposed the law of universal gravitation, is one of the most prominent scientists of that age.

However, as I mentioned thought in the West has long had an ingrained Christian worldview at its foundation.

So, for a long time it was quite difficult and rather dangerous for scientists to contradict this Christian worldview.

But the academic atmosphere changed a lot during the 18th and 19th centuries, and the Christian worldview as an explanation of natural phenomena gradually lost its influence.

It was not until the 19th century that scientific research became an established profession though.

The term ‘scientist’ was coined around 1833 by William Whewell (1794-1866), an English philosopher.

In this sense, we could say that real modern science was established in the 19th century, not the 17th century.

Of course, even today, some individual scientists believe in Christianity or other religions.

Nevertheless, the work of science itself has nothing to do with religion, but proceeds mainly through experiments, observation, and testing of hypotheses.

In fact, skepticism is at the foundation of modern scientific thinking.

We should not believe in any theory as it is.

We should always ask, ‘Is it true?’
And the results of scientific research should be widely disclosed so they can be discussed

by everyone.

In this model, new discoveries and hypotheses are continuously submitted, and the existing ideas are revised when necessary.

This is scientific progress, and it is the method that results from using science as a ‘narrative’ to explain the world.

I said earlier that technology is developed through a process of trial and error that is unrelated to science.

However, technology in the present age is tightly linked to science. That is the strength of today’s technology.

Section 2: The view of nature: the West and China

The Western Mechanistic View of Nature

I said earlier that people everywhere have ‘narratives’ to explain various phenomena in the world.

A ‘narrative’ to explain the world, be it based on science or anything else, is not an ad hoc explanation of individual phenomena.

Rather, behind it is a framework of a larger way of looking at the world.

What was that narrative in Western Europe in the 17th century when modern science began?

The idea is that the natural world is one big machine, made up of parts and a mechanism that makes it function.

The parts are matter, and matter is made up of the smallest units, such as atoms.

Then, forces act between these units, and the mechanism of how they move is determined.

Rene Descartes is said to have been the first to propose this mechanistic view of nature.
I think that, for us, it is rather easy to understand this view of nature, because our current idea of nature is still based on this mechanistic view.

Qi and the Theory of Yin-Yang and the Five Elements

For Japan, the most familiar, and for a long time the most important cultural influence, was Chinese civilization.

At the root of Chinese philosophy and view of nature is the concept of ‘qi’, which is the essence that creates all things and gives them life force.

Qi is something invisible and fluid, and all things come into being when qi changes its form in various ways.

The concept of qi is tightly related to The Theory of Yin-Yang and the Five Elements, which is based on the idea that there are five basic elements of nature: wood, fire, water, metal, and earth, and that each of these elements has two forms: yin and yang (negative and positive).

These five elements are the result of the qi taking form by solidifying.

Up until the Edo period, the Japanese view of nature was the traditional Chinese view based on qi.

So, it was very difficult for scholars of the Edo period, who had only learnt Western science through various books, to master the alternative philosophy, and mechanistic view of nature that it entailed.

It is the same today, it is difficult for us to understand explanations based on qi and Yin-Yang and Five Elements Theory as we have not been exposed to this way of thinking in recent times.

Nevertheless, the scholars of the Edo period struggled very hard to grasp the ideas of modern science, and in the end, managed to do that.

Section 3: Scientific Standards of the Edo Period

Now, let us look at science during the Edo period in Japan.

In this section we will determine what the academic standards in Japan were at that time.

However, academia includes many different areas of investigation, and we cannot cover all of them, so let us take some examples from astronomy.

Calendars and Astronomy: TAKAHASHI Yoshitoki

Compiling a calendar is especially important for both governance and livelihood activities such as farming.

Therefore, since ancient times, the Imperial Court had a position assigned for the compilation of calendars.

To compile an accurate calendar, an observatory was necessary to measure the movement of celestial bodies.

In 1685, an observatory affiliated with the Shogunate was established in Ushigome, Tokyo.

When Takahashi Yoshitoki was appointed as the astronomer in 1795, the observatory was at Asakusa.

Takahashi Yoshitoki was born in Osaka in 1764.

He was fond of mathematics from his childhood, and became a student of Asada Goryu, who opened a school of astronomy and calendar science in Osaka.

It is said that Goryu was quite a remarkable astronomer, who observed sunspots and Saturn's rings, and independently discovered Kepler's laws of planetary motion.

Japanese astronomy during the Edo period was quite noteworthy.

Together with Hazama Shigetomi (1756-1816), who was also a student at the school, Takahashi had the opportunity to learn about Ptolemy's geocentric theory and Kepler's theory of the elliptical motion of the planets through books that introduced Western astronomy through China at the time.

In 1795, the Shogunate decided to revise the calendar that had been in use until then, and Takahashi Yoshitoki was assigned as the compiler of the new calendar.

Takahashi applied his own latest research to compile the new calendar.

He adopted Kepler's theory which he learnt from that book, but he rejected Ptolemy's geocentric theory and adopted the heliocentric theory of Copernicus.

At that time, Copernicus' heliocentric theory had just been introduced to Japan, but he adopted it based on his own observations.

The new calendar turned out to be very, very accurate.

Hazama Shigetomi, who was Takahashi's assistant, came from a wealthy merchant family in Osaka.

He was interested in “*karakuri*” from childhood and contributed to the development of observation instruments such as telescopes.

He also made a great contribution to training craftsmen to make such instruments.

Thus, in the latter half of the Edo period, a wealthy class of merchants started to expand, and people from this class studied and invented various observation instruments as a hobby.

This creation of instruments demonstrates the depth of intellectual activities in the Edo period.

It was this skill that enabled Takahashi to conduct astronomy based on actual observations.

Isolation and information from the West

The Edo period was a time of national isolation.

In 1549, Francisco Xavier of Spain came to Japan for the purpose of propagating Christianity.

Since this visit was during the Warring States Period, Japan could not respond in a unified manner, and Christianity gradually spread in Japan.

Some of the war lords who converted to Christianity even tried to donate their territories to the Roman Catholic Church.

However, Toyotomi Hideyoshi (1537-1598), the unifier of Japan, saw the danger that such a situation would bring, and in 1587 he issued a decree banning Christianity.

After a series of incidents and feuds, the Edo Shogunate cut off diplomatic relations with Spain in 1624 and banned Portuguese ships from coming to Japan in 1639.

Thereafter, it was forbidden for Western ships to come to Japan, for Western goods to be imported, and for Japanese to travel to Southeast Asia.

This was called national seclusion.

As a result, Japan did not become a colony of the Western powers and was able to protect its own culture.

At the same time, however, it also cut off the flow of information about the Western world, which was developing rapidly at that time.

This was during the 17th and 18th centuries, a time when modern science was born and developed.

The Shogunate understood the disadvantage in not receiving this information and decided to build Dejima in Nagasaki as the place they would accept scientific and technological exchange with the Netherlands.

From then on, Japan would acquire the latest information about Western Europe only through negotiations with the Dutch, and Western learning would come to be known as "Dutch Studies.”

On the other hand, fearing the spread of Christianity, the Shogunate banned the importation of any books on religion in 1630.

Scientific books, including those on astronomy, could not be imported if they contained references to Christian ideas.

The eighth Shogun, Tokugawa Yoshimune whose tenure lasted from 1716 to 1745, was an open-minded man who was interested in Dutch Studies and felt that it was essential to revise the calendar based on Western astronomy.

Therefore, in 1720 he lifted the ban on the importation of scientific books that did not directly teach Christianity.

This ensured the future importance of Dutch Studies in Japan.

It is precisely because of this foundation that Takahashi Yoshitoki and others were able to play such an active role.

There were many other Dutch Studies scholars who were also active in the Edo period.

Among the most famous ones were Hiraga Gennai, Udagawa Yoan, and Sugita Genpaku, whose contributions to physics, biology, chemistry, and medicine were noteworthy.

Against this background, the Siebold Affair occurred.

It was discovered that Philipp Franz von Siebold, who was a doctor at the Dutch trading post in Nagasaki and had a profound influence on the Dutch Studies scholars in Japan, had tried to take a map of Japan with him when he returned to the Netherlands in 1828.

It was forbidden to take Japanese maps abroad, and many people were arrested and imprisoned in connection with this incident.

This incident reduced the prosperity of Dutch Studies and temporarily impeded the development of science in Japan.

Nevertheless, in the end, the desire to learn from Western science could not be extinguished, and it continued from then on.

Section 4: The End of the Edo Period, and the Meiji Restoration

Education levels in Japan

From the end of the Tokugawa Shogunate at the time of the Meiji Restoration, Japan entered a turbulent period.

In 1853, the US Navy's East India Squadron, led by Commodore Mathew Perry, arrived in Tokyo Bay with four black ships, and the Shogunate allowed them to land at Kurihama.

The following year, 1854, a Treaty of Peace and Amity between the US and Japan was concluded.

After that, a civil war broke out over whether to retain the Edo Shogunate.

Finally, in 1867, Tokugawa Yoshinobu handed over authority to the Emperor, that is, the return of imperial power.

This period from 1854 to 1867 is called the Bakumatsu, or the end of the Edo period, which was followed by the Meiji Restoration.

This is when Japan’s modernization took off, made possible by the high level of general education in the Edo period.

Terakoya were schools where children were taught to read, write, and perform calculations using the abacus.

The children of both merchants and farmers attended these schools which played a key role in raising the education level of the general public.

In addition, there were feudal clan schools for samurai students which covered basic studies.

There were also private schools such as the Tekijuku in Osaka.

These were for young samurais who had completed their primary and secondary education, to further their education and hone their thinking abilities.

In other words, there existed a strong philosophy of individualism among the samurai according to which, to become a fine human being, one needed to be able to think deeply for oneself.

In Japan, such an attitude toward learning was cultivated from the Edo period.

<u>Ogata Koan and Kawamoto Komin</u>

Ogata Koan (1810–1863), the third son of a low-ranking samurai from current Okayama Prefecture, grew up in Osaka.

From an early age he had read books on Dutch studies by the scholar Shizuki Tadao.

Later, he went to Edo (Tokyo) to study, and to Nagasaki to expand his learning.

He became an exceptional and renowned doctor.

In 1838, he started a private school for Dutch studies—the Tekijuku in Osaka.

Amongst the students who studied at this school were Fukuzawa Yukichi, Omura Masujiro, Hashimoto Sanai, and many others who were active during the early Meiji era.

His Tekijuku played a significant role in Japan's modernization from the end of the Tokugawa Shogunate to the Meiji Restoration.

As a physician, Ogata is famous for his contribution to the prevention of smallpox by learning of Edward Jenner's vaccination method and implementing it in Japan.

Although initially shocked by the arrival of the Black Ships, Ogata strove to develop human resources who could compete with Western Europe and America by teaching the natural sciences, as 'Western' studies, to the next generation of young people.

It can be said that his work bore fruit beautifully. Fukuzawa Yukichi, a student at the school, later went on to found Keio Gijuku (today's Keio University) which was designed based on the education provided at the Tekijuku.

Kawamoto Komin (1810–1871) was the third son of an Osaka feudal clan doctor.

He was a student of Tsuboi Shindo, a Dutch studies scholar in Edo, and a classmate of Ogata.

He inherited the efforts of Udagawa Yoan (another 19th-century Dutch studies scholar) and others and became a pioneer who brought modern chemistry to Japan.

Kawamoto began by translating a German book on chemistry and established the Japanese term for 'chemistry.'

He also coined new Japanese words for 'protein,' 'atmosphere,' 'synthesis,' and others, to better explain and popularize modern chemistry.

Shimazu Nariakira, who became the feudal lord of the Satsuma domain in 1851, hired Kawamoto to translate and teach from books on Western armaments, weapons, photography, and other subjects.

Then, just three years after the arrival of the Black Ships, the Satsuma domain completed Japan's first steamship, the Unkoumaru.

There is a theory that the Western powers, having witnessed such technological prowess, recognized Japan's strength, and gave up on colonizing it in the way they did with other Southeast Asian countries.

Young Japanese students abroad

During Bakumatsu and the Meiji-restoration period there were many young samurai who were sent overseas to learn about western culture, science and technology.

Many of those people became students in western universities and graduated with high marks.

On return they made tremendous contributions to the modernization of Japan.

Among the hundreds of those ambitious Japanese young people, I want to mention one woman who was sent to the United States when she was just 6 years old, Tsuda Umeko.

She was sent to George Town, Washington DC. in 1871 by the Meiji Government and stayed there for 11 years.

Later she went to the US again and graduated from Bryn Mawr College.

After she came back to Japan, she made quite an effort to improve women's education and established a women's college.

The Meiji Restoration and the Employment of Foreign Advisors and Experts

In addition to sending many brilliant young Japanese to western countries as students, the Meiji government employed many foreigners.

O-yatoi Gaikokujin were, as the expression suggests, foreigners who were hired by the

Shogunate and the government to help modernize Japan during the later Edo and early Meiji periods.

Although the country was closed to the outside world during the Edo period, Dutch nationals such as Philipp Franz von Siebold were nevertheless hired as foreign policy advisors in Nagasaki.

After the country was opened to the outside world, the Meiji government aimed at developing new industries, a strong military, and a wealthy nation, to be on an equal footing with the Western powers of the time.

To achieve these goals, the government focused on importing political and legal systems, industries, technologies, and academics in general from the developed countries.

In addition to serving as government advisors and in other government positions, foreigners were assigned to educational institutions such as the Imperial College of Engineering and Tokyo Medical School, both predecessors of the University of Tokyo, and Keio University, to educate young Japanese.

Most of these foreigners were from England, France, Germany, and America, and by around 1900, more than a thousand people from each of these countries were employed.

Edward Morse (1838–1925), an American zoologist, became a Professor at Tokyo Imperial University in 1878, where he taught zoology and anthropology.

He discovered the shell mounds at Omori (Tokyo) and was also the originator of the study of biological anthropology and archaeology in Japan.

In addition, many foreigners were hired to teach engineering, agriculture, medicine, and language courses.

Their appointments were usually for two or three years, but some of them settled permanently in Japan.

Some of their writings from that time give us a clear picture of how the Japanese people of the Meiji era perceived themselves, and how the hired foreigners perceived the situation in Japan.

For example, Erwin Bälz (1849–1913), a German physician, was invited to teach at the University of Tokyo Medical School in 1876, and his stay in Japan lasted 29 years.

In ‘Bälz’s Diary,’ he left behind many valuable observations on Japan.

He was alarmed that the Japanese, in their zealous pursuit of modernization, sometimes expressed the opinion that Japan had neither culture nor history, and that it all begins here and now.

He noted that these Japanese critics denounced the country’s ancient culture and history as barbaric; and he added that a country that does not recognize the excellence in its own culture will not be respected by other countries.

As for his thoughts on leaving the University of Tokyo, he said, ‘Japanese people want hired foreigners to sell only the fruits of learning, but hired foreigners are trying to be gardeners who grow the trees of learning. Japanese people seem to think that it is enough to receive the latest results, instead of trying to understand the fundamental spirit of science.’

Bälz made some significant points which require thoughtful consideration.

Even now, more than 150 years after the Meiji Restoration, I believe these points have important suggestions for all of us.

Section 5: The Two World Wars, the Post-War Rapid Growth Period, and Now

Military-driven Science in Japan during the Meiji, Taisho, and Showa Eras

During the Meiji era, Japan successfully instituted policies to enrich and strengthen its military and promote new industries, rapidly expanding its national power.

In 1894, Japan’s intentions conflicted with those of China, leading to the first Sino–Japanese War.

In 1904, Japan clashed with the Russian Empire, which was planning to move southward, igniting the Russo–Japanese War.

Despite the overwhelming superiority in equipment, troops, and national finances of both China and Russia at the time, Japan prevailed.

During the short Taisho era (1912–1926), Japan fought in the First World War (WWI), which began in Europe.

Because of the Anglo–Japanese Alliance, Japan entered the war as an ally of Britain.

Thus, Japan was also among the victors in that war.

The Showa period began in 1926 and the Second World War (WWII) began in 1939.

Then Japan attacked Pearl Harbor in 1941, declaring war on the United States and launching World War II's Pacific War.

During this war, the Allied and Axis powers developed increasingly powerful weapons and military technologies, including nuclear bombs.

Germany surrendered unconditionally in May 1945.

Three months later, the Allies dropped atomic bombs on Hiroshima and Nagasaki, and Japan surrendered unconditionally, ending World War II.

The military technologies developed during World War II for encrypting and decoding wireless communications fuelled the development of computer and communication technology, just as advancements in atomic physics fuelled the development of nuclear power and propulsion technologies.

The wartime innovations in science and technology changed the society forever.

The United States developed the first atomic bombs, supported by Canada and the United Kingdom, through the Manhattan Project, a research and development program involving thousands of engineers and physicists.

One among them was the American theoretical physicist Richard Feynman, who was awarded the Nobel Prize in Physics in 1965.

He published a book in 1985, *Surely You're Joking, Mr. Feynman!* , which became very popular.

In this book he wrote how the physicists in the Manhattan Project enjoyed the research on building up an atomic bomb.

Many of the scientists later brooded over the essential horror of atomic weapons.

Yukawa Hideki (1907–1981) and Tomonaga Shinichiro (1906–1979) were two of Japan's outstanding atomic physicists.

The Japanese Navy, which was secretly conducting an atomic weaponry research program known as Project F, invited Yukawa to lead the research, but the war ended before Project F produced any results.

In 1949, Yukawa became the first Japanese to be awarded the Nobel Prize in Physics.

In 1965 Tomonaga shared the Nobel Prize in Physics with Richard Feynman.

After World War II, Tomonaga became a founding member of the Pugwash Conferences on Science and World Affairs, a group of scholars, scientists, and public figures working to eliminate all weapons of mass destruction.

Rapid Economic Growth and the Role of Private Companies' Research

From 1955 to 1973, Japan underwent a rapid period of economic development.

Japan shifted its primary energy source from coal to oil, building numerous large-scale petrochemical complexes and advancing Japan's heavy chemical industry.

Automobile use became widespread, stimulating the 'motorization' of society.
Unfortunately, this was also a time of unconstrained environmental destruction and pollution problems, with disastrous consequences like the Minamata disease caused by mercury poisoning.

Recognising the need for change, Japan began implementing protective and remedial measures to purify river water quality, regulate automobile exhaust emissions, and improve engine efficiency.

Universities have always been the primary centres of scientific research.

However, during its period of rapid economic growth, Japan supplemented universities' general science research with research institutes owned by private companies.

This figure shows the number of publications in the research field of physics in Japan from 1975 to 2015.

The number of papers published by corporate laboratories increased rapidly until around 1995, playing a critical role in driving science in Japan.

This pattern is more or less the same as for all other fields of research.

The Toyota Physical and Chemical Research Institute

Now, I visited one of those corporate research institutes, the Toyota Physical and Chemical Research Institute located near Nagoya, and asked Dr. Kikuchi Noboru, how these great contributions by private companies were realized during the Showa period.

Dr. Kikuchi:
Especially after World War II, corporations had to go beyond just dealing with individual parts. Consider the internal combustion engine of cars.
People think it simply sprays gasoline and burns it. But how do you spray the gasoline? And how do you burn it?
To answer that, you need to know about electricity. You need knowledge about material.

Prof. Hasegawa:
So perhaps corporations took a step back and looked at the entire process, and decided they needed to carry out a wide range of research on their own.

Dr. Kikuchi:
Instead of creating a research lab inside the company and looking at individual technologies, they had to think about what would happen when they integrated everything.
It was crucial to carry out research with interdivisional cooperation.
As time passes, the material evolves, and things get computerized.
Semiconductors come into play as well. I think what's most striking is that post-World War II corporations of Japan did an excellent job keeping up.

Prof. Hasegawa:
In the future, colleges and corporations may work toward different goals,
but I feel it will become necessary for them to cooperate.

Dr. Kikuchi:
Corporations will have to ask college professors and national research institutes for help or propose a collaborative effort.
I see that as inevitable for advancement.

Prof. Hasegawa:
We can find further evidence on the strength of a company's research abilities by considering the experience of Japan's Nobel Laureates: Esaki Leona, Tanaka Koichi, Akasaki Isamu, Amano Hiroshi, Nakamura Shuji, and Yoshino Akira.

All whom were awarded the Nobel Prize for physics or chemistry, and all did their research in Japanese private corporations.

However, when the bubble economy burst, the volume of research output from Japan's corporate research institutes began to decrease in the areas of electronics and pharmaceuticals.

In 2004, after Japan's national university system was partially privatised, subsidies to national university corporations for operating expenses began declining by 1% every year.

These changes affect the desire of today's young people to decide to pursue careers as researchers.

This figure shows the change in the percentage of undergraduates who entered master courses and the percentage of students holding master's degrees who entered doctoral programs between 1990 and 2012.

The number of students entering doctoral programs decreased from 16.1% in 1990 to 9.6% in 2012 and it stayed about the same level since then.

One reason is that it is almost certain that many of them fear that a research career might not be as reliably lucrative as it once was.

However, I do not give up hope.

As I said at the beginning of this program, science is an activity based on the curiosity that is a universal part of human nature.

It will not be extinguished easily.

Section 6: Conclusion

Japan had not had a particularly close relationship with Western Europe until the 17th century.

Modern science started in the West during the same 17th century, and Japan rapidly absorbed new scientific ideas during the Edo period despite the policy of national isolation.

And Japan eventually succeeded in incorporating science and science-based technology in its society during the Meiji Restoration (1868-1912).

I think that Japan, throughout its long history, has cultivated a tradition of thinking originally in its own way, and thus led to 25 Nobel laureates in science since 1949.

The value we place on science and technology can have global consequences that affect areas from transportation and communication to AI and climate change.

To advance science, we need ideas nurtured by curiosity to increase human understanding of the natural world.

Investing in and aspiring to increase humanity’s shared knowledge can catapult us beyond short-term successes to accrue innovations of lasting and exemplary value to humans.