From: D.G. Wittner, P.C. Brown, eds., *Science, Technology, and Medicine in the Modern Japanese Empire* (Routledge, 2016), 193-210.

12 The question of research in prewar Japanese physics

Ito Kenji

Introduction

A primary challenge that James Bartholomew addressed in *The Formation of Science in Japan: Building a Research Tradition* was the establishment of a tradition of scientific research in Japan, an issue that this chapter revisits by examining some of the problems that confronted noted prewar physicists in their efforts to integrate their research activities within the international scientific community and subsequently to develop their own tradition of physics research.[1] Here the word research means methodical and institutional activities conducted to produce new knowledge, not learning established knowledge from others. Shaped by various characteristics of the time and debated among its historical actors, what actually constitutes research is contingent and contentious. Nonetheless, physicists' research efforts can be examined from an historical perspective.

Physics research in Japan was not necessarily part of empire building. Since research is an activity to produce knowledge, its relevance to empire building was not inherent, even if it was contingent on that process. As many Japanese in the late nineteenth and first half of the twentieth century, physicists in Japan did not necessarily have all aspects of their work immersed in empire building. As was the case with other imperial powers, however, imperialism and colonialism shaped the social contexts in which research activities took place. The question might be how the context of empire building affected physics research in Japan and vice versa.

Sociologists and historians have discussed the relation between science and its social contexts for half a century.[2] The ways by which scientific research affected society constitutes a prevalent theme in popular accounts of the history of science.[3] Various attempts have been made since Robert K. Merton's and Paul Forman's seminal work to show how social contexts shaped scientific contents and research activities.[4] For example, there is a renewed attempt to explain scientific content through social context during the Cold War.[5] It is, however, problematic to separate scientific content and social context, and to attempt to explain the former by the latter, because such dichotomous reductionism is groundless. This applies to science and empire building, too.

Analyzing empire building and science in Japan, the temptation to reduce scientific activities to things related to empire building is strong. As Bartholomew suggests in his afterword, Westerners often impute uniqueness or particularity to Japan as a society. Seeing Japanese scientists as loyal servants of Japan's empire building might appeal to some readers who approach this genre with Orientalistic curiosity, intending to see Japanese science as different, peculiar, or even unique, and forgetting the complicated relation between science and colonialism in Europe.

By contrast, this chapter approaches the issue of physics research and empire building with extreme caution. In particular, I avoid the semiotic topography to include scientific activities within empire building. Basic physics research and empire building were separate activities with separate goals. At the same time, they were intertwined with various, and significant, intersections. This chapter tells a more ambiguous story than some might expect.

As symbolized by several Nobel laureates, physics is one of the fields in which Japan has displayed impressive strength in scientific research. One can safely say that Japanese physicists started producing strong research before World War II. I have discussed elsewhere the rise of quantum physics in Japan, which marked the creation of a strong research tradition in the country. My focus was on how scientific cultures in Japan received and adapted to the research culture of quantum physics.[6]

Here, I attempt a rough illustration of a different approach to locate physics research in Japan in historical contexts. My assumption is that establishing a research tradition was not simply a process of achieving a pre-defined goal, but a resolution to a set of questions and problems confronting physicists. These questions are partially constructs of the analyzer since the historical actors did not consciously formulate or endeavor to solve them. They also reflect the actual problems that confronted scientists. These questions might well be within the personal and individual spheres of each physicist. Then again, they might be in the external spheres, which concern time, space, and society. Here I examine Japanese physicists who contributed to the establishment of Japan's research tradition and how they responded to these questions. Weaving a historical narrative through such questions and the physicists who confronted them, I eschew asking the simplistic question of how the "context" affected the "content" of research.

Without pretending to be comprehensive, I focus on four questions: the questions of possibility, legitimacy, strategy, and originality of research.

The question of possibility concerns whether it was possible to conduct physics research in Japan, either for Japan as a society or for individuals. This was an especially valid question during the Meiji era. When racial prejudice was common, a lack of observable evidence that the Japanese were capable of research could also be considered sufficient to assume they were incapable. Moreover, even if the Japanese were inherently capable of research in physics, whether it was possible for Japanese physicists to compete with researchers in Europe and North America was another matter. While Japan's socio-cultural environment may have not been nearly so encouraging of research, Japan is geographically separated from Europe and, at the time, journals took at least two weeks to arrive.[7] The question of possibility is thus not only a matter of personal capacity but also a matter of social conditions, broadly defined.

The question of legitimacy concerns how research initially became a legitimate activity in Japan. Since research seeks new knowledge, it is often an exploration of the unknown and a quest for new ideas. The content of new knowledge is by definition impossible to predict and can have unexpected results. Results might be insufficiently beneficial to justify the expense or might have undesirable impact. Researchers often challenge the orthodoxy when they produce new knowledge. They develop an ethos to challenge orthodoxy, and new ideas can shake established social norms. Consequently, research is potentially risky, costly, and subversive. For an individual, therefore, conducting research requires a certain mindset that incorporates their own sense of the legitimacy of their work. Whether society even allows and/or supports research activities as legitimate is a socio-cultural question. For a country, supporting research activities may not be a reasonable allocation of national resources. Because doing research was not the norm in pre-Meiji Japan, the emergence of research as a legitimate activity requires an explanation. In this context, the question of legitimacy was often tied to Japan's empire building. Although Japanese scientists were not necessarily mindless minions of the empire, the cause of empire building and its associated goals of industrial development and military research were rationales that research-oriented scientists could use to justify their activities. It was not simply because research could produce scientific weapons, but also because research could enhance the status of the empire in industry, commerce, and prestige.

The question of possibility is connected to what I tentatively call the question of strategy: what strategies could Japanese physicists employ to produce research? Of what opportunities (and resources) could and should they take advantage? I do not assume Japanese physicists always made conscious decisions in choosing their strategies. Instead, this line of analysis attempts to examine possible options allowed by the scientists' socio-cultural situation, such as the state of the scientific community, the status of research organizations, other available resources, and the tangible choices that individual scientists made.

The question of originality pertains to the question of strategy—and points to the fundamental question of introducing Western science. In the Japanese context, conducting scientific research was a potentially contradictory enterprise. On the one hand, modern scientific research came to Japan from Europe and North America. Conducting research involved the use of conceptual and practical tools invented in Europe, which might encourage the imitation of Western practices and thoughts. On the other hand, conducting research was supposed to produce new knowledge, which critically hinged on the researcher's creativity and originality. How to achieve originality is the apparent dilemma.

Kitao Diro (Jirō) and local science

Among early Japanese scientists, Kitao Diro (1854–1907) has received little attention from historians. In 1869, at age 16, Kitao went to Germany to study medicine. After spending two years at a gymnasium, he entered the University of Berlin, switched his major to physics, and studied under Hermann Helmholtz and Gustav Kirchhoff until he returned to Japan in 1883. During his unusually long stay, Kitao was immersed in the Helmholtzian tradition of physics and physiology. In 1878, he wrote and published a doctoral thesis, *Zur Farbenlehre*, in which he described his invention of *Leukoskop*, an optical instrument for diagnosing color blindness.[8] After his return to Japan, Kitao obtained a position at the College of Science, Tokyo University.[9] His scholarship, however, did not take root in Japan's physics. A confrontation with Kikuchi Dairoku, a mathematician trained in Britain and a member of the powerful Kikuchi-Mitsukuri family, led to Kitao's departure from the College of Science in 1886. He subsequently became a professor of "agricultural physics and meteorology" at the College of Agriculture of the Imperial University of Tokyo, where in 1887 he published a three-part paper on typhoons.[10] Demonstrating Kitao's mastery of late nineteenth-century mathematical physics, the study involved a rigorous application of fluid dynamics in a meteorological phenomenon. Highly regarded by meteorologists outside Japan, this original study was one of the earliest theoretical treatments of the typhoon.[11]

Three aspects of Kitao's work pertain to the question of strategy. First, he was able to learn his skills in mathematical physics during his extended stay at a prime research circle in Berlin. Kitao's training was scarcely distinguishable from that of contemporary German scientists. Second, Kitao specialized in theory, which suffered relatively little from the lack of a physical infrastructure, making it possible for him to do noteworthy work even after his return to Japan. Third, he chose a local phenomenon, typhoons, as his topic. Although it is not certain how much it mattered in Kitao's theoretical work, Japanese scientists have used this strategy repeatedly in order to turn their inherent geographical marginality into an asset. Therefore, earth science was an area to which European and American physicists hired by the Meiji government paid particular attention. Early physicists in Japan (Japanese and non-Japanese) achieved early success in this field. In addition to meteorology, seismology was another good example of an area representing early research success.[12]

Topics of local scientific interest may have provided an advantage relative to the question of legitimacy. Scientific understanding of typhoons appeared to be especially useful and socially legitimate in a country where typhoons cause serious damage. This, however, led to the development of another discipline separate from physics. Consequently, this work did not lead to Kitao's legitimization as a mathematical physicist. He is typically considered a precursor of Japanese dynamic meteorology.

Nagaoka and the Japanese capability for research

After Kitao, and representing the struggle to conduct research in Japan, was Nagaoka Hantarō (1865–1950). Nagaoka was a wide-ranging research-oriented physicist. His most important work, the Saturnian model of the atom, was one of the earliest scientific achievements by Japanese scientists relevant to mainstream physics. Mentoring younger researchers and serving as an administrator at scientific institutions, Nagaoka was a towering figure in Japan's physics community.[13]

Nagaoka's research orientation was not the norm and he appeared to be deeply unhappy about the circumstances of physics research in Japan. After World War II, remembering the environment of physics departments in the early twentieth century, Nagaoka criticized his colleague, Tanakadate Aikitu, for not conducting research. When a younger physicist, Fujioka Yoshio, later asked whether Japanese physicists had started doing research when new issues of physics journals had arrived in Japan, Nagaoka laughed and declared that that would have been impossible when Tanakadate had been in charge.[14]

As a student, Nagaoka was seriously concerned with the question of possibility. He held fundamental doubts regarding Japanese capabilities for scientific research. In 1883, after finishing the first year at Tokyo University, he took a one-year leave of absence and turned to the Chinese classics for evidence of scientific research by Asians. He found a number of examples of how ancient Chinese scholars investigated natural phenomena, such as *Zhuangzi*, which provided both a description and explanation of lightening based on the theory of *yin* and *yang*. Nagaoka considered that explanation essentially correct and in the same vein as the modern scientific theory of positive and negative electricity. To his surprise, *Zhuangzi* also raised the question of the sky's blue color, a question later answered by the British scientist John Strutton (Lord Rayleigh). Similarly, Nagaoka claimed that there were various descriptions of natural phenomena in the Chinese classics of the Warring States period. Hui Sui, a logician who often appears in *Zhuangzi*, for example, discussed the issue of the infinitesimal, asking the question of repeating the operation of breaking a stick into two halves. From these examples, Nagaoka concluded that Asians were indeed curious and capable of systematic scientific research.[15]

Nagaoka was aware of the question of legitimacy and was keen on connecting physics with practical applications. For him, atomic physics was not an abstract scientific theory devoid of practical utility. In early twentieth-century atomic physics, the electron was probably the most important and most studied object. This was also the case with quantum mechanics, which was, in practice, mostly a theory of electrons. As a theory of electrons, atomic physics was considered especially relevant to the rapidly developing discipline of electrical engineering, which people widely thought would rebuild the modern urban landscape. Thus, Nagaoka and other physicists of his generation wrote popular accounts and textbooks of electron theory, which naturally included atomic theory.[16]

For Nagaoka, the link between physics and its practical applications was not limited to electrical engineering. Spectroscopy, for example, was an experimental sub-discipline of physics important to atomic physics and to Japan's optical industry. Nagaoka's later interest in the transmutation of elements was at least partially legitimized by its practical value, in particular the transmutation of mercury into gold, in which Nagaoka toiled for years to no avail.[17] Nonetheless, this idea of the transmutation of elements resurfaced when Nagaoka endorsed and called for support for Nishina Yoshio's efforts to construct cyclotrons.[18]

As for the questions of strategy and originality, Nagaoka was inclined to reduce these issues to the question of mentality and personal traits. He ascribed his success with the Saturnian model to his "rashness" in publishing his work—in spite of criticism from colleagues. He described later generations (and implicitly his contemporaries) as "too timid" in comparison to himself.[19]

Nakamura Seiji on the Imperial Institute for Physical Research and RIKEN

Nakamura Seiji (1869–1960) was an experimental physicist at Tokyo Imperial University. He is of interest primarily because of his justification for research, not his own research. In March 1908, Nakamura published an article in *Jiji shinpō* calling for the establishment of a "*Teikoku Rigaku Kenkyūjo*" (Imperial Institute for Physical Research).[20] According to Nakamura, the most important measure for the survival of the nation was *fukoku kyōhei* ("rich nation, strong army"). The best way to achieve this, Nakamura argued, was to be progressive and to develop commerce and industry. He argued that fundamental to the development of commerce and industry was establishing an imperial research institute. Nakamura also argued that a research institute would enhance Japan's standing internationally. Nakamura supported his argument by providing the example of *Physikalische Technische Reichsanstalt*, the German research institute for physics and engineering, funded by donations from Werner Siemens. Nakamura praised Siemens as a "true patriot" and sought donations from the rich to establish such an institute in Japan.[21]

Although Nakamura's idea did not materialize at the time, other scientists, especially chemists Takamatsu Toyokichi and Takamine Jōkichi, repeated his argument in subsequent years, emphasizing the utility of chemical research for a newly developing chemical industry.[22] As a result of the experience of World War I, an institute was eventually established as the first research-oriented organization in Japan, the Institute for Physical and Chemical Research, or RIKEN, in 1917.

RIKEN was originally established as a research institute for chemistry and physics, with the hope that its research results would contribute to the development of heavy industry in Japan. It was a non-government organization, originally funded by donations from the imperial household and the industrial sector, as well as annual grants from the government.[23] Its functions soon multiplied.

RIKEN's third director, Ōkouchi Seibin, appointed in 1921, made it an institution where pure scientific research and empire building coexisted. He solved the problem of funding by industrializing research results through RIKEN itself and later RIKEN Sangyōdan, the industrial concern under Rikagaku Kōgyō, a stock-holding company that he created in 1927. A specialist in military engineering and a prominent member of the House of Peers, Ōkouchi obviously had Japan's empire in mind and considered research in physics and chemistry a scientific basis for developing Japan's heavy industry, an important source of national wealth, and a necessary step for modernizing Japan's armaments.[24]

RIKEN was successful in producing scientific knowledge, but not so much for the development of Japan's heavy industry. RIKEN was able to industrialize some of its scientists' research. A large portion of the profit was returned to RIKEN. One early example was industrialization of vitamin A. Because of this funding, researchers at RIKEN were able to enjoy abundant funds and freedom, a research environment far better than what was to be found at the imperial universities. Ironically, because of the assumed utility of its research, RIKEN created an ideal place for pure research, viewed as a "free paradise of scientists."[25]

Ōkouchi was less successful as an industrialist. Compared to other newly emerging industrial concerns such as Nissan, Nicchitsu, Shōden, or Nissō, RIKEN's interests and impact on society were much more limited, consisting of very small companies specializing in one product with a fragile financial base, many of which stopped producing profits. In 1939, Ōkouchi was removed from power and RIKEN underwent reform to separate profitable and unprofitable companies.[26]

Terada Torahiko and experimental physics

Even if being Asian did not actually prevent the Japanese from being capable of conducting scientific research, it obviously did not guarantee research abilities. Furthermore, there were other disadvantages and obstacles, such as the geographic separation of Japanese scientists from European scientific centers and the stimulus of close professional contacts. Distance prevented them from receiving the latest scientific news in a timely manner and keeping in touch with colleagues overseas.

Overwhelmed by these difficulties, Terada Torahiko (1878–1935) sought an alternative strategy. Terada was a professor of experimental physics at the Imperial University of Tokyo as well as chief scientist at RIKEN. Although he was one of the best-known scientists in Japan, Terada is recognized more for his literary essays based on science than for actual scientific research. Early in his career, Terada sought success in mainstream physics topics. Inspired by Max von Laue's work, in the 1910s Terada conducted research on X-ray diffraction.[27] While von Laue used photography, Terada found a way to observe diffraction patterns using a fluorescent screen. In 1913, he published two short articles in *Nature* and one long article in *Proceedings of the Tokyo Mathematico-Physical Society*.[28] Around the same time, however, William Lawrence Bragg, along with his father William Henry Bragg, developed the famous work that has come to be known as Bragg's law and the idea of net planes. Their work laid the foundation for X-ray crystallography, which resulted in their Nobel Prize in 1915.[29]

While the Bragg's work overshadowed Terada's, Terada was at least able to choose the right scientific problem and make progress toward an important finding. Had he been given a better research environment, he might have produced results comparable to Bragg's. In this sense, the kind of question that Nagaoka asked, namely the question of whether the Japanese possessed the inherent ability to do scientific research, was no longer as pressing as the external disadvantages from which Japanese physicists suffered. If geographic isolation made communication with European and American research centers difficult, the lack of experimental facilities and equipment was equally confounding. Terada used a second-hand X-ray tube donated by the Faculty of Medicine, which was apparently better funded and equipped than the Faculty of Science.[30]

These difficulties compelled Terada to give up competing with European and American physicists. Instead, he opted to find research topics that European scientists would not think of, or with which they would have a disadvantage, such as local natural phenomena. In Terada's case, it was geophysics, especially seismology. The other research category involved various artifacts and everyday natural Japanese phenomena. While his 1907 doctoral thesis was an acoustic study of the traditional Japanese bamboo flute, he studied topics such as small fireworks, the expulsion of wisteria seeds, and the falling motion of the camellia flower.[31]

Choosing such non-mainstream and somewhat eccentric topics was probably Terada's answer to the question of originality. One of his students, Uda Mititaka (Michitaka), reported that Terada encouraged them not to imitate foreigners but instead attempt to find rare phenomena, explaining, "In physics, too, we don't have to imitate Westerners. There must be a kind physics suited to the Japanese."[32] Terada simultaneously created a tradition of scientist-literati, who not only produced scientific research but also literary work based on scientific knowledge.

Positioning himself in this situation, Terada created a niche for his own variety of Japanese physics. Ultimately, Terada's combination of scientific research and literary skill provided the means to legitimize research in physics quite differently from the legitimation of physics in engineering. Research could be valued from literary, and aesthetic perspectives could be further justified by a wider readership outside the scientific community.

Whether Terada's research activities were completely unrelated to Japan's empire building is debatable. After all, Terada belonged to RIKEN, and some of his research had relevance to military technology and industrial applications.

Yet, conceptually, Terada opened a space for research in which physicists were able to justify their work without resorting to the rhetoric of empire building.

Ishiwara Jun and modern physics

Unlike experimentalists like Terada, theoretical physicists did not require a significant material environment for research. Nonetheless, to be successful and have access to up-to-date information on developments in the field, theoretical physicists needed to have intellectual interaction with research centers. Japanese physicists could visit international research centers. Another strategy was to choose a novel research topic for which such a research center did not yet exist (e.g. the work of Terada Torahiko and Kitao Diro).

Ishiwara Jun's (1881–1947) strategy was similar. Ishiwara was one of the most successful theoretical physicists in the generation immediately after Nagaoka. Upon graduating from the Imperial University of Tokyo in 1906, he studied relativity and quantum theory, publishing a paper on the former in 1909, the latter in 1911.[33] These publications appeared before he spent time abroad studying in Europe from 1912 to 1914. During his stay in Europe, Ishiwara visited and studied with important theoretical physicists, including Arnold Sommerfeld in Munich, Max Planck in Berlin, and Albert Einstein in Zurich.[34] In 1915 Ishiwara produced his most important paper, a study on quantum conditions.[35] After returning to Japan, he was appointed professor of theoretical physics at the newly founded Tohoku Imperial University, which was intended to be a new research center in science and technology. In 1921, however, Ishiwara resigned the post because of repercussions from a scandal caused by his extramarital love affair.

Although Ishiwara's shortened scientific career failed to create a strong research tradition of theoretical physics at Tohoku Imperial University, he thereafter became a prominent science writer. Through popular lectures, articles, and books, he promoted the new physics, relativity theory, and quantum theory. He also facilitated Einstein's 1922 visit to Japan. These activities were extremely important in popularizing modern physics in Japan and enhancing its legitimacy. Indeed, Ishiwara's writings generated support for physics and lured young people, including future physicists such as Tomonaga Sin-itiro and Yukawa Hideki, into the field.[36]

Einstein's high regard for Ishiwara's 1909 relativity theory paper suggests that Ishiwara was already able to produce significant research before his trip to Europe.[37] Ishiwara's quantum conditions turned out to be similar to Arnold Sommerfeld's findings, a generalization of Niels Bohr's quantum conditions.[38] Of note, Ishiwara published his paper in Japanese half a year before Sommerfeld, yet historians of physics indicate this particular work had only limited impact.[39] It, however, indicates that Ishiwara had the ability to participate in the mainstream development of quantum theory and produce first-rate research in theoretical physics and to contribute substantially to major developments in physics, yet remained hampered by slow communications. As was the case with Kitao, research in theoretical physics required less physical infrastructure; therefore, its lack or deficiency caused fewer problems than in experimental physics. A lack of access to timely information and intellectual stimulation could still cause difficulties. This disadvantage was mitigated somewhat by the novelty of relativity theory and quantum mechanics. Because they were both still relatively new, even in Europe, researchers were similarly dispersed and conducting their research independently. Ishiwara's study abroad should have helped him to make closer contacts with European theorists but he failed to have much influence on European physicists partly because Ishiwara published in a Japanese journal, and partly because World War I severed communications between Germany and Japan. Ultimately, Ishiwara was not successful in raising the visibility of his work.

Like Terada, Ishiwara had the qualities of a literary person and was known for his *tanka* poetry. Ishiwara's biographer and historian of science, Nisio Sigeko, points to Ishiwara's early interests in the aesthetic aspects of nature and suggests that they might have actually been what led him to become a theoretical physicist. Being from the relatively poor Christian pastor's home, physics was a good compromise for Ishiwara, satisfying his literary and aesthetic proclivities, while simultaneously conveying potentially more useful training for finding a remunerative job.[40]

Nishina Yoshio and atomic physics in Japan

Nishina Yoshio (1890–1951) is arguably the most important physicist in pre-World War II Japan. Originally trained as an electrical engineer, he turned to physics after graduating from the Imperial University of Tokyo and entering RIKEN. Nishina stayed in Europe, mostly in Copenhagen, between 1921 and 1928. As a theoretical physicist, he is known for his 1929 Klein-Nishina formula, one of the earliest contributions to quantum mechanics by a Japanese scientist.[41] He led a team of experimentalists and initiated cosmic ray and accelerator physics in Japan.[42] Most importantly, he trained young physicists, both in theory and experimentation, contributing significantly to the creation of a strong research tradition. During World War II, he led the Japanese Army's nuclear bomb project, *Ni-go kenkyū*.[43] After the war, he became RIKEN's director (renamed KAKEN in 1948) and served as a statesman of science, working to rebuild science in Japan until his death in 1951.[44]

In terms of his research in theoretical physics, Nishina used strategies similar to Kitao and Ishiwara. During his long stay in Europe he acquired the requisite skills to conduct research in the emerging tradition of quantum physics. One difference was that Nishina's stay in Copenhagen coincided with a period of fundamental change in physics, the birth of quantum mechanics. This was soon followed by radical developments in experimental physics, including the use of radioactive substances and accelerators that represented tremendous opportunities for physicists attempting to "catch up" with European research.[45] Simultaneously presenting new problems and new methods, Japanese physicists were able to reduce the advantage that European researchers enjoyed over physicists in the periphery. An added difference is that Nishina not only acquired the requisite skills to do theoretical physics, he also brought back a way to develop a community of physicists in Japan.[46]

Even greater than his contributions to theoretical physics, Nishina is credited with creating a strong tradition of experimental nuclear physics in Japan. Nishina was particularly quick to adopt the new methodologies of experimental physics, namely cosmic ray research and the use of cyclotrons. Nishina laid groundwork that eventually led to a tradition of cosmic ray and high-energy physics in Japan. Initially, his strategy was most likely designed to overcome Japan's geographic disadvantage. When experimental physics methods were changing radically, Japanese physics could gain a clear advantage by having one of the most powerful experimental devices in the world. He could have chosen to employ clever experimental approaches or to promote superb experimental techniques. However, Nishina probably considered training experimentalists would be even more difficult than gathering the resources to build a large device. He apparently underestimated the difficulty of building a cyclotron. While its construction required significant material resources and proprietary components, what mired construction was Japanese physicists' lack of experience with cyclotrons.[47]

Regarding legitimacy, even more than Nagaoka, Nishina represented the connection between physics and engineering. Coming from a locally prominent but declining farmer's family, in a region where land reclamation continued for centuries, a career in engineering was a natural path to restore the family fortune. Two of his elder brothers entered engineering-related careers and his eldest brother inherited the family's salt-making business. Therefore, it was natural for Nishina to pursue engineering. Completing undergraduate studies, his interests shifted to atomic physics and Nishina entered graduate school (and a paid position at RIKEN). Nishina's choice of atomic theory was justified because atomic physics included studies of electrons, which also provided a foundation for electrical engineering.[48]

To legitimate constructing larger or better scientific instruments necessitated developing social justifications. As Nishina's team required greater resources, he had to spend increasingly more time on fundraising. His students subsequently complained that he spent too much time writing popular accounts, while neglecting their collaborative drafts for academic journals.[49] Japan's nation building provided room for fundraising. Famously, the Japan Society for Promotion of Science funded Nishina's nuclear physics research, because, according to Hirosige Tetu, meteorologists believed cosmic ray research might contribute to aerology, deemed important for aviation.[50] Similarly, the atomic bomb project provided Nishina's group with funding to build a larger cyclotron. A cyclotron could be used purely for scientific research; it could also be used to obtain essential data for atomic weapons. By connecting research with military utility, scientists were able to use empire building to legitimize their expensive research.

Nishina's attitude toward empire building was ambivalent. Elsewhere I discussed the dilemma he faced. Nishina was a socially responsible scientist in his own way, who took seriously his obligations to family, country, teachers, students, and science. He was a firm believer in scientific cosmopolitanism, which his mentor Niels Bohr strongly advocated and from which Nishina greatly benefited. At the same time, Nishina had obligations to his country. He did his best to pursue nuclear research within the material and financial constraints of wartime Japan and had to reconcile multiple and contradictory obligations. He probably tried to achieve this reconciliation by attempting to keep research activities alive during the war as much as he could. Nishina understood that he needed to be ready to resume international competition and collaboration in science at the end of the war. He believed that, if unable to show high standards for his research activities in Japan, he would disgrace the country.[51]

Yukawa Hideki and Tomonaga Sin-itiro

The generation of physicists after Nishina successfully produced first-rate research. Yukawa Hideki (1907–81) and Tomonaga Sin-itiro (1906–79) are two representative examples. Various historians have discussed and contrasted Yukawa and Tomonaga. Olivier Darrigol, in particular, provides a succinct account of their styles. Yukawa was bold and ambitious, whereas Tomonaga was careful and patient. Yukawa attempted to solve problems by radically departing from the basic premises, even by mobilizing Eastern thought (or so he claimed). Tomonaga attempted to solve problems through innovation within existing theoretical frameworks.[52] While I agree with Darrigol's skepticism toward Yukawa's self-fashioning as an East Asian scientist, I interpret Yukawa's references to Chinese and Japanese philosophical traditions as his own perception of how he solved the question of originality and his way of showing this perception to others, especially Westerners (what I call "self-Orientalism"). Tomonaga's style as a "non-reactionary conservative" was another answer to the same question.[53] Their differences appear in their means of connecting with the network of contemporary physicists. Whereas Tomonaga was in the tradition of theoretical physics stemming from Niels Bohr, Yukawa had little direct connection with European research centers. He relied on foreign-trained Japanese physicists such as Hori Takeo, a spectroscopist who spent time in Copenhagen and taught physics to Yukawa and Tomonaga at the Third Higher School.[54] Nishina also encouraged Yukawa and supported his meson theory before Yukawa published in English.[55]

Rather than re-examining differences between Yukawa and Tomonaga, I examined their commonalities in earlier work. In addition to their family origins (both had university professors as parents), they grew up in the same socio-cultural environment. In short, they lived in the modernist culture of the Taishō and early Shōwa eras. Engineering that legitimized physics through practical value produced a new material environment in the urban space of modernist culture. Featuring writers such as Edogawa Rampo, Yumeno Kyūsaku, Inagaki Taruho, and Unno Jūza, the movement was represented by the magazine *Shinseinen* (New Youth), first published in 1920. Inspiring writers of detective stories and science fiction alike, science and technology were important elements in this cultural movement personified by "modern girls" and "modern boys."[56] Those who received a higher education were simultaneously much less integrated into the social elite and Japanese empire building. From 1919 to 1929, the number of college students sextupled. Coupled with a crippled economy, however, this resulted in high unemployment for college graduates, as symbolized by Ozu Yasujirō's 1929 film *Daigaku wa deta keredo*. Unlike students at imperial universities during the Meiji era, Japanese college students were no longer expected to be pillars of the state. This situation radicalized some of them politically, leading to left-wing activism.[57] Although science students were less prone to politics, this cultural and occupational situation must have affected their way of evaluating the question of scientific legitimacy.

To science students, a revolution of a different kind was more directly relevant. The historian of science Kaneko Tsutomu called Einstein's 1922 visit to Japan an "Einstein Shock." A national relativity theory fervor and popular writings on relativity theory by the likes of Ishiwara Jun inspired some young future physicists. Einstein represented a revolution, and that revolution was directly connected to science and technology, which both impressed and thrilled young intelligent minds.[58]

Reality did not match anticipated opportunity, however. Tomonaga was excited by the expectation that he would be able to learn physics when he entered the Imperial University of Kyoto. When he arrived, he found that "In laboratories, people were doing second-hand experiments with dirty and dusty old-fashioned machines. Lectures on theories were flooded with dry equations. How boring it was to copy those equations one by one!"[59]

In response to this uninspiring university environment, Yukawa, Tomonaga, and other young physicists at the Imperial University of Kyoto formed a study group to read literature on quantum mechanics (c. 1927). Tomonaga later described themselves as "ambitious modern boys."[60] Similar groups formed in Tokyo as well.[61]

In 1929, Werner Heisenberg and Paul Dirac came to Japan. Although their visit lacked the popular fervor of Einstein's, it had tremendous impact on young physicists like Tomonaga. Heisenberg and Dirac were only in their late twenties at the time, but they were already immortals in the history of physics; their youthfulness made a tremendous impression on Japanese students. The students were further impressed when Nagaoka, the patriarch of Japanese physics who was more than 60 years old, addressed them as "sensei."[62] More importantly, Tomonaga was able to understand exactly what they were talking about.[63]

By the end of the 1920s, young physicists in Japan at least had answers to the questions of legitimacy and possibility. Modernism provided them with the cultural legitimacy that motivated and encouraged them to produce new knowledge in a subject to which few of their teachers paid attention. Empire building was much less important to this generation of cultural elite, who were disenfranchised, politically indifferent, and endowed with cultural capital from their families. Institutionally, they were protected by established organizations like RIKEN or imperial universities, and by leading figures like Nagaoka and Nishina. Hence, internally and externally, they no longer needed to tie justification for research related to empire building. Simultaneously, seeing Heisenberg and Dirac, they realized that first-rate research in physics was not entirely out of their reach.

Conclusion

The question of possibility, whether the Japanese were capable of doing research in physics, found a tentative answer in Nagaoka's personal inquiry into the Chinese classics. Nagaoka proved the point by his own achievement in physics. Other physicists, such as Terada and Ishiwara followed, eventually leading to Yukawa's work on meson theory in 1935.

How to answer the question of legitimacy depended on individual scientists and their socio-cultural circumstances. Earlier generations socially legitimized research in physics by connecting it to engineering. There were also individuals, such as Terada and Ishiwara, whose literary interests constituted at least part of the values they personally saw in physics research. Much less integrated into the elite class of the Japanese establishment, later generations of physicists could more easily legitimize research activities in the personal and cultural sphere, such as the context of the modernist cultural movement of the Taishō and early Shōwa eras.

Depending on the subject and the stage of its development, the answer to the question of strategy varied. A common problem was Japan's geographic marginality. Experimentalists had the added challenge of requiring experimental facilities and equipment. For theorists, a lack of communication with foreign scholars represented another dilemma. It was generally difficult to gain visibility among scientists overseas, and Japanese researchers' results often failed to exert significant influence even when their work was noteworthy.

There were two contrasting approaches to the question of originality in Japan. Terada and Yukawa attempted to emphasize a unique Japanese or Asian approach. Nishina and Tomonaga tried to be original within the same framework as Western scientists. The latter was not simple mimicry. In the case of Kitao, we cannot say he was imitating Western scientists when this classification did not apply to his classmates at the University of Berlin with whom he studied. Similarly, when Tomonaga studied quantum electrodynamics, he probably had more in common with Heisenberg and Dirac, at least scientifically and most likely culturally, than with earlier Japanese physicists, or than Heisenberg and Dirac had with European scientists before quantum physics. As the natural world was described by the newly developing quantum physics, the social world of modernist culture engendered by technological developments was new to both Europeans and Japanese. In this

environment, the question for Japanese physicists was not how to introduce Western science to Japan, but how to adapt to the emerging physics, which was new to both the Europeans and Japanese.

The question of how Japanese physicists established their tradition of research in physics and integrated it within the international network of researchers involves various sub-questions. While I do not claim that these four questions exhaust the relevant possibilities, they represent at least some of the important issues that need to be addressed. In addition, they are useful in highlighting the various options of historical actors with different specialties at different times.

Empire building and physics research were separate yet intertwined activities. As we saw with Nakamura and the establishment of RIKEN, physicists could use empire building to justify the research activities that they envisioned. There were also overlaps, where the same activities had both meanings. For example, Nishina's wartime nuclear weapons project can be seen as pure scientific research and as a part of military effort. But it is a mistake to simply subsume physics under imperial agendas.

Notes

1 James Bartholomew, *The Formation of Science in Japan: Building a Research Tradition* (New Haven, CT and London: Yale University Press, 1989).

2 For a review of sociology of science, see Steven Shapin, "Here and Everywhere: Sociology of Scientific Knowledge," *Annual review of Sociology*, 21: (1995), 289–321.

3 For a recent prominent example in this genre, see Thomas Hager, *The Alchemy of Air: The Jewish Genius, a Doomed Tycoon, and the Scientific Discovery that Fed the World but Fueled the Rise of Hitler* (New York: Broadway Books, 2009).

4 Robert K. Merton, *Social Theory and Social Structure* (New York: Free Press, 1968), especially Chs XVIII and XIX; Paul Forman, "Weimar Culture, Causality, and Quantum Theory: Adaptation by German Physicists and Mathematicians to a Hostile Environment," *Historical Studies in the Physical and Biological Sciences*, 3, (1971), 1–115; Paul Forman, "*Kausalität*, *Anschaulichkeit*, and *Individualität*, or How Cultural Values Prescribed the Character and Lessons Ascribed to Quantum Mechanics," in *Society and Knowledge*, ed. Nico Stehr and Meja Volker (New Brunswick, NJ: Transaction Books, 1984), 333–47.

5 Naomi Oreskes and John Krige (eds), *Science and Technology in the Global Cold War* (Cambridge, MA: MIT Press, 2014).

6 Kenji Ito, "Making Sense of Ryōshiron (Quantum Theory): Introduction of Quantum Mechanics into Japan, 1920–1940" (Ph.D. dissertation, Harvard University, 2002).

7 Tomonaga Sin-itiro, Oda Minoru, Takeuchi Masa, Kumagai Hiroo, Yamazaki Fumio, Sugimoto Asao, Ishii Chihiro, and Fujimoto Yōichi, "Nishina sensei to kakubutsuri no hatten: Nishina Yoshio sensei no 10 shūnen o mukaete 1 & 2," *Shizen*, 26: 4 (1971), 55–76, 73.

8 Diro Kitao, *Zur Farbenlehre* (Berlin: G. Lange (Paul Lange, 1878).

9 Founded in 1877, Tokyo University took various names through its history. In 1886, it became the Imperial University. When Kyoto Imperial University was established in 1897, it was renamed Tokyo Imperial University. In 1949, it was reorganized and renamed Tokyo University.

10 Hirota Isamu, "Kitao Diro no shōzō: Kishōgaku no idai na sendatsu," *Tenki*, 57: (2010), 909–16; Diro Kitao, "Beiträge zur Theorie der Bewegung der Erdatmosphäre und der Wirbelstürme," *Journal of the College of Science, Imperial University, Japan*, 1: (1887), 113–209; 2: (1889), 229–412; 3: (1895), 293–402.
11 Hirota, "Kitao Diro," 913–4.
12 See Kim Boumsoung, *Meiji Taishō no Nihon no jishingaku: Rōkaru sainesu o koete* (Tokyo: University of Tokyo Press, 2007).
13 Itakura Kiyonobu, Kimura Tōsaku, and Yagi Eri, *Nagaoka Hantarō den* (Tokyo: Asahi Shinbunsha, 1973).
14 Nagaoka Hantarō, Fujioka Yoshio, and Watanabe Nei, "Genshiryoku jidai no akebono," in *Nagaoka Hantarō, Genshiryoku jidai no akebono, Ningen no kiroku* (Tokyo: Nihon Tosho Sentā, 1999), 181–207, 187.
15 Ibid., 192–5; Itakura *et al.*, *Nagaoka Hantarō den*, 39–44.
16 Kenji Ito, "Superposing Dynamos and Electrons: Electrical Engineering and Quantum Physics in Nishina Yoshio," in *Traditions and Transformations in the History of Quantum Physics*, ed. Shaul Katzir, Christoph Lehner, and Jürgen Renn, Edition Open Access (Berlin: Max Planck Research Library for the History and Development of Knowledge, 2013), 183–208.
17 Itakura *et al.*, *Nagaoka Hantarō den*, 473–508.
18 Nagaoka *et al.*, "Genshiryoku jidai," 135–6.
19 Ibid., 191.
20 I note that in this context, *rigaku* can be either physics or science. I tentatively translate this as physics because Nakamura's idea came from *Physikalische Technische Reichsanstalt.*
21 Nakamura Seiji, "Teikoku rigaku kenkyūjo setsuritsu no hitsuyō," in *Seikatsu, kagaku, kyōiku* (Tokyo: Kawade Shobō, 1938), 10–30.
22 Kamoi Takeshi (ed.), *Kōgaku hakushi Takamatsu Toyokichi den* (Tokyo: Kagaku Kōgyō Jihōsha, 1932).
23 Saito Satoshi, *Shinkō kontsuerun RIKEN no kenkyū* (Tokyo: Jichōsha, 1987), 361–3.
24 Ibid.
25 Tomonaga Sin-itiro, "Kagakusha no jiyū na rakuen," in *Tomonaga Sin-itiro chosakushū*, vol. 6 (Tokyo: Misuzu Shobō, 1981, 2001), 224–35.
26 Saito, *RIKEN no kenkyū*, 358–61.
27 Paul Forman, "The Discovery of the Diffraction of X-rays by Crystals," *Archive for History of Exact Sciences*, 6: (1969), 38–71.
28 Torahiko Terada, "On the Transmission of X-rays Through Crystals," *Proceedings of the Tokyo Mathematico-Physical Society*, 7: (1913), 60–71.
29 William, L. Bragg, "The Diffraction of Short Electromagnetic Waves by a Crystal," *Proceedings of the Cambridge Philosophical Society*, 17: (1913), 43–57.
30 Nishikawa Shōji, "Raue hanten," *Shisō*, 16 March, (1936), 103–6.
31 Torahiko Terada, "Acoustical Investigation of the Japanese Bamboo Pipe, syakuhati," *The Journal of the College of Science, Imperial University of Tokyo, Japan*, 21: (1907), 1–34.
32 Uda Mititaka, "Umi no butsurigaku no chichi: Terada sensei no omoide," *Shisō*, 166, (March 1936), 61–7.
33 Jun Ishiwara, "Zur Optik der bewegten ponderablen Medien," *Proceedings of the Tokyo Mathematico-Physical Society*, 2nd Series, 5: 10 (1909), 150–80; Jun Ishiwara, "Beiträge zur Theorie der Lichtquanten," *Tohoku Science Report*, 1: (1912), 67–104.
34 Nisio Sigeko, *Kagaku jānarizumu no senkusha: Hyōden Ishiwara Jun* (Tokyo: Iwanami Shoten, 2011), 145–56.
35 Jun Ishiwara, "Die universelle Bedeutung des Wirkungsquantums," *Proceedings of the Cambridge Philosophical Society*, 2nd Series, 8: 4 (1915), 106–16.
36 Nisio, *Ishiwara*, v–ix.
37 Ibid., 69.

38 Arnold Sommerfeld, "Zur Quantentheorie der Spektrallinien," *Annalen der Physik*, 51: (1916), 1–94.
39 Helge Kragh, *Niels Bohr and the Quantum Atom: The Bohr Model of Atomic Structure* (Oxford: Oxford University Press, 2012), 154.
40 Nisio, *Ishiwara*, 18–9.
41 Oskar Klein and Yoshio Nishina, "Über die Streuung durch freie Elektronen nach der neuen relativistischen Quantendynamik von Dirac," *Zeitschrift für Physik*, 52: (1929), 853–68.
42 Dong-Won Kim, "Yoshio Nishina and Two Cyclotrons," *Historical Studies in the Physical and Biological Sciences*, 36: 2 (2006), 243–73.
43 See for example, Yamazaki Masakatsu, *Nihon no kakukaihatsu, 1939–1955: Genbaku kara genshiryoku e* (Tokyo: Sekibundō Shuppan, 2011), 3–66; Walter E. Grunden, *Secret Weapons and World War II: Japan in the Shadow of Big Science* (Lawrence, KS: University Press of Kansas, 2005), Ch. 2; Keiko Nagase-Reimer, *Forschungen zur Nutzung der Kernenergy in Japan, 1938–1945* (Marburg: Japan-Zentrum Philipps-Universität Marburg, 2002).
44 One biography of Nishina available in English is Dong-Won Kim, *Yoshio Nishina: Father of Modern Physics in Japan* (New York: Taylor and Francis, 2007).
45 I owe this insight to Takabayashi Takehiko, who applied a similar idea to the developments in the 1930s. See Takabayashi Takehiko, *Variete: Butsuri hito kotoba* (Tokyo: Misuzu Shobō, 1998).
46 I discuss this aspect of Nishina's role in Japan in detail elsewhere. See Ito, "Making Sense of Ryōshiron"; Kenji Ito, "The *Geist* in the Institute: The Production of Quantum Physicists in 1930s Japan," in *Pedagogy and the Practice of Science: Historical and Contemporary Perspectives*, ed. David Kaiser (Cambridge, MA: MIT Press, 2005), 151–84.
47 Kim, "Yoshio Nishina and Two Cyclotrons"; Hinokawa Shizue, *Saikurotoron kara genbaku e: Kakujidai no kigen o saguru* (Tokyo: Sekibundō Shuppan, 2009), Ch. 2.
48 Ito, "Superposing Dynamos and Electrons," 185–7.
49 Tomonaga Sin-itiro, Yamazaki Fumio, Takeuchi Masa, Sakata Shoichi, Nakayama Hiromi, and Tamaki Hidehiko, "Nishina sensei o shinonde," *Shizen*, 6: 4 (1951), 64–76, 71.
50 Tetu Hirosige, "Social Conditions for Prewar Japanese Research," in *Science and Society in Modern Japan: Selected Historicla Sources*, ed. Shigeru Nakayama, David L. Swain, and Eri Yagi (Tokyo: University of Tokyo Press, 1971), 202–20.
51 Kenji Ito, "Values of 'Pure Science': Nishina Yoshio's Wartime Discourse Between Nationalism and Physics, 1940–1945," *Historical Studies in the Physical and Biological Sciences*, 33: (2002), 61–86.
52 Olivier Darrigol, "Yukawa, Tomonaga, and the Japanese School of Theoretical Physics," in *Seimitsu kagaku no shisō* (Tokyo: Iwanami Shoten, 1994), 211–30.
53 Ibid., 227.
54 Okamoto Takuji, "Sankō jidai no Yukawa Hideki to Tomonaga Sin-itiro," *Butsuri*, 57 (2002): 419–20.
55 Yukawa Hideki, "Nishina-sensei no omoide," in *Yukawa Hideki chosakushū*, ed. Katō Shūichi (Tokyo: Iwanami Shoten, 1989 [1951]), 96–100.
56 Ito, "Making Sense of Ryōshiron," 151.
57 Ibid., Ch. 3. For student activism in prewar Japan, see Henry DeWitt Smith, *Japan's First Student Radicals* (Cambridge: Harvard University Press, 1972).
58 For Yukawa, see Yukawa Hideki, *Tabibito: Aru butsurigakusha no kaisō* (Tokyo: Kodansha, 1966). For Tomonaga, Tomonaga Sin-itiro, "Wagashi wagatomo," in *Tomonaga Sin-itiro chosakushū*, vol. 1 (Tokyo: Misuzu Shobō, 2001), 193–202. For general cultural impacts of Einstein's visit to Japan, see Kaneko Tsutomu, *Ainshutain shokku* (Tokyo: Kawadeshobō Shinsha, 1991), especially vol. 2, 220*ff.*

59 Tomonaga, "Wagashi wagatomo," 193.
60 Ibid., 196.
61 The activities of this group of young physicists are studied in Katsuki Atsushi, *Ryōshirikigaku no shokkō no nakade* (Tokyo: Seirinsha, 1991). See also Ito, "Making Sense of Ryōshiron," Ch. 3.
62 Katsuki Atsushi, *Sone Take: Wasurerareta butsurigakusha* (Tokyo: Sekibundō Shuppan, 2007), 206.
63 Ito, "Making sense of Ryōshiron," 261.