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1.4 Human Resources for Science, Technology, and Innovation

TOMIZAWA Hiroyuki[1]

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Abstract

Although the importance of human resources for science, technology, and innovation is widely recognized, there are various policy issues related to them. Major issues include the mismatch between the system to develop human resources in science and technology and the needs of industry and society, various problems arising from the mismatch between the supply and demand of research personnel, and the inadequate utilization of highly specialized human resources by society as a whole. The basic concept of human resources for science, technology, and innovation is ambiguous and weak, and this has led to a lack of in-depth policy discussions and deliberation.

Keywords

Human resource development system, supply and demand of human resources, human resources in science and technology, research personnel, highly skilled human resources

1Senior Research Officer, Research Group 2, National Institute of Science and Technology Policy, Ministry of Education, Culture, Sports, Science and Technology

1. Scope of Policy Issues Related to Human Resources for Science, Technology, and Innovation

The development and promotion of using human resources for science, technology and innovation is an important issue in science, technology, and innovation policy. Since “people” are responsible for science, technology, and innovation, it is only natural that “human resources” should be a major theme. From this perspective, policy issues related to human resources for science, technology, and innovation emerge, such as what kind of human resources should be developed for future innovation and solutions to social issues, and how to establish a human resource development system for this purpose.

It is also necessary to view the various problems that have arisen in Japan’s innovation system in relation to the “human resource development system.” For example, there has been widespread concern in recent years that Japan’s “research capability” is declining, and this may be partly due to problems in the training and supply of personnel with PhDs, the treatment of young researchers, and the research environment. It is becoming increasingly important to consider these issues from the perspective of the human resource development system. It is also important to examine the issue of the lack of progress in the use of information technology in Japan from the perspective of the human resource development system in information technology.

This alone shows that policy issues related to human resources for science, technology, and innovation are wide-ranging, but there are many other issues that cannot be captured in the above perspective. Therefore, an exhaustive or systematic investigation of the issues is difficult. The following sections will provide an overview of the problem, with emphasis on the basic concepts and key issues underlying the various issues.

2. Conceptual Framework for Human Resources for Science, Technology, and Innovation

2-1. Overview of the Concept of Human Resources for Science, Technology, and Innovation

Hitherto, the term “human resources for science, technology, and innovation” has been used, but it is ambiguous and it is unclear what kind of human resources it refers to and what scope it covers. While ambiguity may be useful in some cases, caution should be exercised when using the term to refer to policy or the subject of policy discussions. Although there are statistical definitions of “human resources in science and technology” and “R&D personnel,” which are considered to be sub-concepts of “human resources for science, technology, and innovation,” there has been confusion surrounding these terms for many years, as described below. Thus, when discussing human resources related to science, technology, and innovation, it should be noted that there are weaknesses in the most basic concepts. This section deals with that issue and will provide an overview of where the problem lies, given that it is difficult to clearly define terms and concepts such as “human resources for science, technology, and innovation” at this point in time.

First, it is appropriate to use the term "human resources for science, technology and innovation" in a broad sense to refer to "human resources who are responsible for activities related to science, technology, and innovation." Although this alone does not clarify what kind of human resources is being referred to, it may serve as an initial term to broadly define the target when discussing policy, for example, "What kind of human resources should be developed to promote science, technology, and innovation?" This term will continue to be used in this paper to refer to a broad range of human resources. The OECD and European Commission, which have provided concepts and definitions of human resources in science and technology and R&D personnel in the past, have described the term as equivalent to "human resources for science, technology, and innovation" using the generic noun phrase, "human resources for the science and technology innovation policy area" in their international database on science, technology, and innovation policy, "STIP COMPASS" (European Commission and OECD 2019). This suggests that, at this time, there is no internationally established definition of "human resources for science, technology, and innovation."

For a more concrete human resource concept, it should be recalled that science, technology, and innovation are rather distant concepts in the first place, and that the term (or concept) "science, technology, and innovation" has only relatively recently come to be used in policy discussions and debates. Therefore, it is natural to divide "human resources for science, technology, and innovation" into those related to science and technology and those related to innovation. Additionally, the former (human resources related to science and technology) has been the subject of policy discussions from early on and there has been relative progress in its conceptualization and definition. Therefore, the concept and definition of human resources related to science and technology will be discussed in Section 2-2, and based on this, the concept of human resources related to innovation will be discussed in Section 2-3.

Next is a brief discussion of concepts related to the concept of "human resources." In the context of our discussion thus far, the term "human resources" has been used to refer to the concept of "human capital" in labor economics, which refers to the skills, techniques, and knowledge embodied in human beings. Until now, the knowledge of labor economics has not necessarily been used or referred to in discussions and examinations of science, technology, and innovation policies. It should be noted, however, that labor economics has conducted various studies and examinations based on the concept of "human capital," which may provide useful knowledge for various discussions and examinations of human resource-related issues.

2-2. Concept of Human Resources in Science,Technology, and Related Concepts

(1) Human Resources in Science and Technology as a Technical Term: HRST

"Human resources in science and technology" is a concept that is well established among experts in statistics and data related to science and technology, as well as among professionals involved in human resource issues related to science and technology. It has been shaped through academic discussions and years of work on statistics in several countries and was presented in the Canberra Manual: Manual on the Measurement of Human Resources Devoted to S&T, compiled and published by the OECD and the Statistical Office of the European Commission in 1995

(OECD/Eurostat 1995). The Canberra Manual is one of a series of manuals published by the OECD that present international standards for the measurement of scientific and technological activities, and covers various matters related to the measurement of human resources in science and technology.

The manual includes the definition of "Human Resources devoted to Science and Technology (HRST)," which is equivalent to "human resources assigned to science and technology" or "human resources engaged in science and technology," but could also be reworded as "human resources in science and technology." The definition is "a person who successfully completed education at the third level in an S&T field of study, or who did not formally qualify as above-mentioned, but is employed in a S&T occupation where the above-mentioned qualifications are normally required." The first half of this definition is based on education and qualifications, while the second half is based on the occupation in which one is engaged. This is a typical way of defining the scope of a certain category of personnel in terms of two aspects: education/qualifications and occupation/activities.

The manual's definition refers to a fairly broad range of human resources and is likely a much broader concept than the term "human resources in science and technology" might suggest. The first half of the definition implies that all persons who have completed a course of higher education in a scientific or technological field are included in HRST. This "course of higher education" is not limited to the graduate level, but in the case of Japan, includes both four-year universities, junior colleges, and technical colleges. The scope of "science and technology fields" is essentially defined as natural sciences and engineering, but the framework is also envisioned to include agriculture, medicine, social sciences, and even humanities in some cases. The second half of the definition, in contrast, includes persons employed in science and technology-related occupations that typically require such education or qualifications, as described in the first half, even if they do not have such education or qualifications. For example, this would include those working in systems engineer positions without higher education. The term "science-related human resources" in Japan may be relatively close in meaning as a general term that refers to the human resource category similar to HRST.

When the Canberra Manual was published in 1995, few countries were conducting statistical surveys on human resources with such a broad scope, and the manual was more of a philosophical document than a practical manual. However, since then, the number of countries that have promoted data management for human resources in science and technology has gradually increased under the influence of the manual, especially in Europe, where the European Commission promotes the management of data in compliance with the manual. In the U.S., the National Science Foundation (NSF) and other organizations have compiled extensive statistics on personnel educated in science and technology at institutions of higher education and those employed in jobs related to science and technology long before the manual was published. This U.S. human resource statistic is essentially based on a concept similar to HRST.

The term HRST does not externally contain the element of "innovation," but is closely related to "innovation" in terms of content and history (Kobayashi 2011, Ayabe 2018). For example, the opening statement of the preface to the Canberra Manual states, "how science and technology (S&T) and human resources (HR) are combined will be a key factor in economic development and human survival over the coming decades," suggesting that the concept of HRST reflects the idea of human resources as those who are responsible for the maintenance and development of society and the economy rather than those who support science and technology systems (OECD/Eurostat 1995).

(2) Definition and Classification of R&D Personnel

In R&D statistics, R&D personnel is a major measurement item along with R&D expenditures. In the OECD's Frascati Manual2, which sets the international standard for R&D statistics, "R&D personnel" are defined as "persons in a statistical unit engaged directly in R&D, whether employed by the statistical unit or external contributors fully integrated into the statistical unit's R&D activities, as well as those providing direct services for the R&D activities."

These R&D personnel are classified as "researchers," "technicians," and "other supporting staff" according to their roles in R&D. In all of these cases, the term "researcher" includes not only those in academic research positions, but also those engaged in "research and development" in companies, for example, since they are those directly involved in "research and development" as defined in the Frascati Manual.

In the definition and classification of R&D personnel, particular consideration should be given to institutions of higher education. University faculty members are included as "researchers" only if they are engaged in research. In the case of Japan, all university faculty members are included as researchers because of the firm principle that "universities are composed of both teaching and research." In the R&D statistics, if a university faculty member does not spend all of their work time on research, they are treated as a part-time researcher rather than a full-time researcher, and this number is measured in terms of "full-time equivalent." In contrast, doctoral students engaged in R&D activities are included as researchers, while master's students are only included as R&D workers if they are paid for the R&D activities in which they are engaged. Furthermore, post-doctoral fellows who are engaged in R&D activities as young researchers at institutions of higher education, public research institutions, or similar, are not treated uniformly, since their activities, or forms of employment and salary, are diverse, and are treated according to the definition and aggregation criteria for R&D personnel as set forth in the Frascati Manual.

2 *The Frascati Manual* is an international guideline on research and development statistics produced by the OECD. Its first edition was published in 1963 and endorsed by OECD member countries in 1964. The name was derived from the name of a place in Italy where a meeting was held to formulate the manual, and was initially a common name, which later became the official name. The manual has since been revised several times, the latest version at this time being the 2015 edition (OECD 2015).

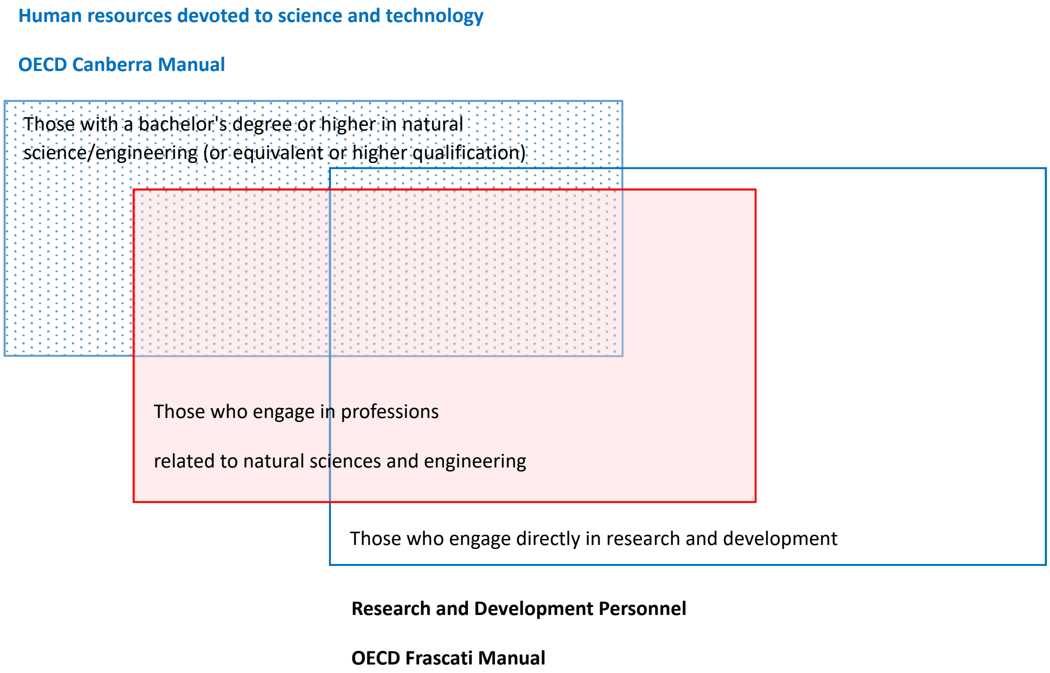

Figure 1: Relationship between Human Resources in Science and Technology (HRST) and R&D Personnel

Note: In this section, the scope of "human resources in science and technology" is limited to natural sciences and engineering. If the scope is expanded to include all fields, including the humanities and social sciences, "R&D personnel" essentially becomes a subset of "human resources in science and technology."

(3) Confusion between "Human Resources in Science and Technology" and "R&D Personnel"

As described above, there are definitions for "human resources in science and technology" and "R&D personnel," and the relationship between the two can be shown in Figure 1, but conceptual confusion can often be seen. First, with regard to "human resources for science and technology," apart from the aforementioned definition, the term is often used as a vague term that simply combines two common noun phrases, "science and technology" and "human resources." In such cases, not only is there ambiguity, but also the problem of confusion between "human resources in science and technology" as a defined term and "human resources in science and technology" as a generic noun phrase, or not knowing which meaning is being used. Moreover, the term "human resources in science and technology" is widely used, and there are cases where policy discussions have been held under such circumstances; however, the discussions have not been furthered.

Another typical example of a problem is when the term “human resources in science and technology” is used, but the content describes “R&D personnel” or “research personnel,” which is an even narrower definition of the term[3]. It is easy to surmise what problems this will create. Policy issues related to “research personnel” will often be internal to the research system, including issues related to the posting and treatment of researchers and the research environment. Meanwhile, as mentioned above, “human resources in science and technology,” defined as HRST, was originally a concept formed in the context of how to link science and technology to the maintenance and development of society and the economy, rather than from the internal perspective of the science and technology system. Therefore, for example, when policy discussions are conducted on human resource needs in response to society and the economy, if the term “human resources in science and technology” is used but discussions are conducted with “research personnel” in mind, the discussions will be closed within the science and technology system and will not be furthered.[4]

(4) Related Concepts of Human Resources in Science and Technology

There are several terms similar to “human resources in science and technology,” but recently the terms “STEM worker,” “STEM workforce,” and “STEM Labor Force” are sometimes used. STEM is an acronym for “Science, Technology, Engineering, and Mathematics” and is increasingly used worldwide, including in Japan, to refer to science, technology, engineering, and mathematics as an educational field. Although STEM refers to a field of education, it is inherently closely tied to the concept of human resources in science and technology, as it originally came to be used in the U.S. to refer to fields of education that needed to be strengthened in the context of the shortage of high-tech talent and the need for human resources that would determine the nation’s industrial competitiveness. The term “STEM workforce,” which refers to personnel with higher education in STEM fields, is similar in scope to HRST.

The terms “highly skilled” or “highly skilled worker” and “highly skilled professionals” are also used relatively often internationally. In response, Japanese words equivalent to “high-level human resources,” “highly qualified human resources,” and “highly skilled human resources” have been applied. Although these terms do not explicitly include a “science and technology” component, it is often used in the context of science, technology, and innovation policy to mean something similar to HRST. In the concept of emphasizing the high degree, the meaning is more limited to researchers and engineers in advanced scientific and technological fields, PhD holders, or similar, rather than to human

3 For “research personnel,” there is no definition that has been circulated internationally, but since it is a complete subset of “R&D personnel” as defined in the Frascati Manual and the relationship between the two is clear, the two terms are both used in this paper according to the content. For example, university faculty members are included in the definition of “R&D personnel” in the Frascati Manual, but the term “research personnel” is sometimes used since they are rarely engaged in “development.”

4 In a related discussion, Kobayashi (2004b), after cautioning about the difference in the meaning of scientist and researcher, makes a point to the effect that in Japan, the discussion is based on the idea that scientist equals researcher, and that policy discussions will not be deepened under such a perception.

resources in science and technology in general. Currently, however, the term is often used primarily to address the issue of the international mobility of human resources involved in science, technology, and innovation.

2-3. Consideration of the Concept of "Innovative Human Resources"

Since the term "science and technology" refers to specialized bodies of knowledge or activities related to such bodies of knowledge, the term "human resources in science and technology" can be thought of as referring to personnel who have specialized knowledge in science and technology or who are involved in specialized activities. In contrast, the term "innovative human resources" is ambiguous as a concept even if it is defined as "human resources involved in innovation." This is because innovation is a highly uncertain event, and it is impossible to predict in advance whether or not it will occur. In other words, it is difficult to define "innovative human resources" based on the activities in which they are engaged. Therefore, when using this term, it is necessary to clarify its meaning according to its purpose.

One way to define "innovative human resources" is to broaden the definition to include those who are involved in activities that have the potential to bring about innovation. This would include all human resources in science and technology in a broad sense, as well as those who are involved in the practical application of scientific and technological knowledge and its application to social systems, or the operators of institutions and organizations that are involved. However, while such a broad view may be useful in some cases, there is a risk that too broad a category of human resources could make it a less useful human resources concept.

The contrasting view is to use the term or concept to refer to human resources engaged in activities that are clearly intended to generate innovation. For example, it could be the founder of a venture or start-up company. Furthermore, experts and others who support industry–academia partnerships and knowledge transfer from universities could be included here, as they are characteristic of the modern innovation system and are a particular focus of today's innovation policy.[5] However, this can create problems, such as targeting only a fairly limited pool of talent and capturing only a portion of the innovation that occurs from unexpected sources.

Even if the emphasis is on the human resources responsible for innovation, there is scope to consider whether it is necessary to capture this in the concept of "innovative human resources." For example, if it is based on the idea that the source of innovation is science and technology, then the concept of "human resources in science and technology" as the core human resources responsible for innovation may be sufficient in many cases. Of course, since innovation comes not only from science and technology but also from management and organizational reform, "human resources in science and technology" alone may not be sufficient in some cases. Even in this case, there is a view that the above-

5 Many of these specialized personnel are found at universities, including "program managers" for R&D projects, "University Research Administrators" (URAs) who are primarily responsible for the management of research activities, and "coordinators for industry–academia–government collaboration" who are responsible for the management of intellectual property and creation of new businesses. Moreover, experts in intellectual property management, personnel involved in building relationships with society, and activities such as outreach and fundraisers are also relevant human resources.

mentioned concept of "highly skilled human resources" will suffice. As described above, the need for the term and concept of "innovative human resources" has not been fully examined, has not been fully accumulated historically, and is not an established concept at this time.

3. Key Policy Issues Related to Human Resources for Science, Technology, and Innovation

This section addresses the main policy issues related to human resources for science, technology, and innovation. Since policy issues emerge based on perceptions and analysis of the state of Japan's science and technology innovation system, the emphasis here is on explaining the circumstances and history behind each policy issue.

3-1. The Mismatch Between the Science and Technology Human Resource Development System and the Needs of Industry and Society

The promotion of science and technology and the creation of innovation require human resources with expertise and a highly developed human resource development system, including institutions of higher education. However, it is not easy to adapt such a human resource development system to the needs of industry and society, taking into account future changes as well, which often results in a mismatch. Although these mismatches can occur for all categories of human resources for science, technology, and innovation, what has actually occurred on a large scale in Japan thus far is essentially a mismatch concerning "human resources in science and technology" in the sense described in Section 2. Since there has been considerable analysis and research on these issues, this section discusses the issue of the mismatch between the system for fostering "human resources in science and technology" and the needs of industry and society.

The development of human resources in science and technology at institutions of higher education has a long history as an important policy issue in Japan. This is the issue of how to position universities as a human resource development system that responds to the needs of society and industry, and how to link science and technology to social and economic development. The issue is not confined to the narrowly defined framework of science and technology policy and has been considered and implemented in various policy areas such as education and industrial promotion policies. Additionally, criticisms have been levelled for many years since the latter half of the period of rapid economic growth regarding human resource development in institutions of higher education, that there is a mismatch with the needs of industry and society, or that they do not supply human resources that respond to changes in industry and society; this has been a fundamental issue within this theme (Kobayashi 1996, Yano 2001, Kobayashi 2001, Morozumi, Saito, and Kobayashi 2004, Tomizawa 2021, Tomizawa, Nagane (Saito), and Yasuda 2021).

When discussing this mismatch, the policy of training human resources in science and technology during the period of rapid economic growth is often cited as a successful model to be contrasted with. Specifically, "during the period of rapid economic growth in the late 1950s and 1960s, the strong needs of society and industry led to a substantial expansion of higher education institutions and an increase in the number of science and engineering departments at universities, which contributed significantly to Japan's economic growth." (Anzai 2022) In fact, during the period of rapid economic growth, the higher education system was greatly expanded[6] with an increase in the number of science and engineering faculties, which was called the "science and engineering boom"; moreover, as indicated by the fact that the employment rate of university graduates during this period was consistently over 90%, the Japanese economic system during the period of rapid economic growth was adequately provided with the large number of university graduates that it needed (Ito 1996, Tomizawa 2021). The science and engineering faculties that were expanded during this period continued to develop and supply human resources in science and technology, who were important members of Japan's innovation system[7] for many years afterwards. In this sense, the policy of fostering human resources in science and technology during the period of rapid economic growth appears to be a response to the demands of industry and social needs. This perception is widespread and has in some respects provided a basic framework for considering human resource development in the Japanese innovation system (Sawa 1984, Sato 2011, Anzai 2022).

Since after the period of rapid growth in the mid-1970s to the present, it is often said that the same "success" in human resource development has not been reproduced (Kobayashi 1996). However, while human resource development during the period of rapid growth could be handled by quantitative forecasts of the overall demand for science and engineering personnel, afterward, forecasts that included qualitative factors such as specialized fields and expertise became necessary, making policymaking more difficult (Morozumi, Saito, and Kobayashi 2004). For example, from the 1980s to the present day, there have often been predictions of a future shortage of human resources involved in information technology, and government policies have been put in place to develop these human resources, but there is always a shortage of human resources[8].

With regard to human resources in information technology, it is believed that the types of personnel and abilities required differ depending on the era, such as the recent high demand for human resources in AI technology, and that

6 This significant expansion of higher education institutions and an increase in the number of science and engineering faculties was achieved under various government programs in the period from the late 1950s to the late 1960s. In particular, the "Plan for Increasing the Number of Science and Engineering Students" (also called the "Expansion Plan for Science and Engineering") formulated by the Ministry of Education in February 1961 is linked to the famous "National Income Doubling Plan" (1960) by the Ikeda Cabinet, and is considered an important plan that supported rapid economic growth (Ito 1996, Kobayashi 1996). However, this expansion of universities' human resource development systems was not achieved solely through government policy. Private universities voluntarily increased the number of science and engineering faculties in the absence of sufficient financial support from the government, and their contribution to the "expansion of science and engineering" exceeded that of public universities. The biggest factor driving the "expansion of science and engineering" was the strong need in industry for human resources in science and technology (Tomizawa 2021).

7 The "Japanese innovation system" in this paper refers to the concept of the companies, government, and universities involved in innovation and the interactions among them as a system across Japan. This is the application of the concept of a "national innovation system" to Japan, which is widely used in innovation research and other fields. An explanation of this concept is provided in Section 1.0.3 "Viewing the Innovation Process as a System" of the "SciREX Core Content." (Nagata 2021)

8 An example of a forecast made in the 1980s is from Inui (1989). As a recent example, the "Survey on Supply and Demand of IT Human Resources" published by the Ministry of Economy, Trade and Industry on April 23, 2019 predicted that a shortage and surplus of human resources will occur simultaneously in 2030, with a shortage of 550,000 IT professionals trained in state-of-the-art technology such as AI and IoT, but that there will be a surplus of 100,000 traditional IT professionals in contract development and maintenance operations.

the rapid development of information technology is partly responsible for the mismatch between the supply and demand of human resources (Morozumi, Saito, and Kobayashi 2004). Furthermore, as mentioned earlier, human resource development to meet the needs of society and industry is a comprehensive policy issue, and in the case of Japan, the weakness spanning multiple ministries and agencies in their ability to address policy issues may also be a factor in the mismatch. More serious is the possibility that a shortage of human resources in information technology is hindering the promotion and utilization of information technology in Japan, but that this shortage has not been recognized.

However, there is one area where the human resource development system in universities has expanded since the period of rapid economic growth, reflecting the needs of society. In the health field, the number of university enrollments tripled from 22,561 in 1992 to 68,603 in 2015, and its share of total university enrollments also increased from 4.2% to 11.1% (Tomizawa 2021). This increase came to a halt in the 2016 academic year but has since been followed again by a continued increase in university enrollment in the health field, a consistent long-term upward trend unparalleled throughout the history of Japanese institutions of higher education. This expansion of universities in the health field is thought to be a response to society's strong need for nursing and healthcare professionals. Furthermore, the relaxation of the standards for the establishment of universities by the Minister/Ministry of Education, Culture, Sports, Science and Technology (MEXT) may have had a significant impact on this expansion. However, the direct driving force behind the expansion of universities is the needs of society and industry, and it is believed that this expansion has occurred due to the relaxation of "regulations" that prevented an effective impact (Tomizawa 2021). Furthermore, the relaxation of the standards for the establishment of universities may have a significant negative effect in terms of a decline in the quality of university education. It is widely known that the relaxation of standards for the establishment of universities during the period of rapid growth led to the "inflation" of student capacity and the "mass production" effect in universities, so to speak (Ito 2013). With regard to human resource development, it is difficult to balance such quantitative expansion with ensuring the quality of human resources, and this is one of the major policy issues related to human resource development.

3-2. Problems Related to the Supply and Demand of Research Personnel

The issue of supply and demand for research personnel has become an independent and important theme in science and technology policy in Japan, due to the severity of the problem and historical reasons. Today, the problem is often seen in researchers' difficulty in finding jobs, worsening treatment of young researchers, and the resulting decline in the status of the research profession. Some have also linked this problem to the "decline in Japan's research capabilities" that became apparent in the 2010s (Nagane 2021). This problem is strongly attributed to the mismatch of supply and demand between research personnel trained in graduate schools and research positions. Similar problems have occurred in the past, and it is possible that this is a structural problem that tends to occur in the Japanese university system. In this regard, this section has been separated from section 3-1 because of the different character of this issue from that of the human resource development system, which is shaped primarily for the needs of industry and society.

In considering this issue, a powerful clue is to revisit the rapid expansion of the university system in the 1960s, which is also mentioned in section 3-1. During this period, the demand for university faculty increased and the scale of human resource development by graduate schools expanded. However, once positions for university faculty members and research positions at public research institutes were filled, they did not become vacant again for a long period of time, resulting in a situation of oversupply. In the late 1970s and 1980s, there was a problem of a large number of "unemployed PhDs" in which doctoral graduates and students who had withdrawn from graduate school continued their research in university laboratories instead of finding regular jobs (Nagane 2021).

At the end of the 1980s, this problem temporarily subsided as student capacity increased, and the number of teachers hired increased as the second baby boom generation entered university. However, the expansion of graduate schools in terms of size consistently progressed during the 1980s.9 This is against the backdrop of the strong needs of Japanese industry and the need to strengthen the scientific research system to address the criticism of "taking a free ride on the basic research of others"10; the government also took steps to strengthen the training of researchers by graduate schools and to position graduate schools as core institutions for promoting academic research.11

In the 1990s, the number of graduate schools was further expanded under the policy framework known as the "emphasis on graduate schools." The number of students enrolled in graduate school increased from 98,650 in the 1991 academic year to over 205,000 in 2000, exceeding the goal of "doubling the number of graduate students" proposed in the November 1991 University Council Report. Note that the term "emphasis on graduate schools" essentially refers to a change in the educational and research organization of a university from a traditional undergraduate-based organization to a graduate school-centered organization; in general, it often refers to various reforms of graduate schools, including such organizational changes, as well as the expansion of graduate schools in terms of scale that occurred as a result of such reforms (Kobayashi 2004a).

The rapid increase in the number of graduate students, especially those enrolled in doctoral programs, under the emphasis on graduate school in the 1990s created new problems. Posts at universities and research institutes, which are the main places of employment for doctoral graduates, did not increase owing to tight government finances, and

9 The expansion of graduate schools in the 1980s saw a marked increase in enrollment in master's programs in engineering, which has the largest number of students by discipline; enrollment increased 1.9 times in the 1990 academic year compared to 1980 (Tomizawa 2021).

10 The response of Japan as a whole to the criticism of "taking a free ride on the basic research of others" was not only to strengthen the "university system," but also to strengthen the basic research initiatives of companies and the government's policy response; thus, it is described here as "strengthening the scientific research system." The "scientific research system" here refers to the part of the Japanese innovation system (see footnote 8) that is primarily responsible for scientific research.

11 In 1988, the University Council issued a report "On the Streamlining of the Graduate School System" to promote reform of the graduate school system. Additionally, in May 1991, a report "On the Improvement of Graduate School Facilities" and in November 1991, a report "On the Quantitative Improvement of Graduate Schools" were published, the latter of which proposed the goal of doubling the number of graduate students by 2000.

since companies mainly hired master's degree graduates for R&D positions, it became increasingly difficult for doctoral graduates to find employment (Mizuki 2007, Enoki 2010, Hamanaka 2013).

Under these circumstances, the "Support Plan for 10,000 Postdoctoral Fellows" was implemented in the mid-1990s. The aim of this plan was to support 10,000 postdoctoral researchers, a position for doctoral degree holders to gain experience as researchers, and the goal was included in the first Science and Technology Basic Plan approved by the Cabinet in July 1996 to be achieved by FY2000. The plan was intended to strengthen Japan's research capabilities by increasing the number of young researchers, which there were fewer of in Japan than in Europe and the U.S., by enhancing and strengthening the positions that would serve as "training periods" for young researchers to become full-fledged researchers. However, since the main means of supporting postdoctoral fellows was fixed-term employment, and it was clear that increasing the number of permanent research positions would be financially difficult, at the time this plan was drawn up, it was pointed out that it was a temporary policy (Enoki 2010). There are also scattered instances where the perception of the general public was that the purpose of the program was to provide a place for doctoral graduates, the number of which had increased rapidly due to the emphasis on graduate school.12 Nevertheless, the plan was received rather favorably at the time due to expectations that it would alleviate, even if only temporarily, problems such as the difficulty of finding employment for doctoral graduates, as well as hopes for the revitalization of university research sites (Ledford 2007, Enoki 2010).

Under this plan, the number of persons eligible for assistance increased from approximately 6,000 in 1996 to 10,000 in 1999. Although the goals of the plan itself were achieved, the number of postdoctoral positions at universities and research institutes did not increase, and there was no change in hiring trends in the private sector, which pushed back the age of doctoral graduates who were experiencing employment difficulties and caused the problem of an aging postdoctoral workforce. Moreover, the difficulty in obtaining future career prospects after completing a doctoral program is believed to have been a factor in the tendency to shy away from doctoral studies. Furthermore, the limited job opportunities in Japan have created problems such as brain drain.

Although these issues are directly related to the training of researchers for universities and public research institutions, they are also problems for Japan's innovation system in that the human resource development system has been expanded far from the needs of industry (Kobayashi 2010).

It is pointed out below that the above issues and policy challenges surrounding research personnel in Japan are extremely unique compared to other major developed countries. However, the mismatch between supply and demand

12 Mizuki (2007) describes the plan as "an attempt to help the many graduate students who would otherwise be unemployed by creating a large number of positions as postdoctoral fellows." Although this may include the author's subjectivity and assertions, it can be considered to reflect the general public's perception to some extent, as it is preceded by a list of 10 articles in major newspapers and other media that discussed the "post-doctoral issue" from 1997 to 2006. Furthermore, the entry for "Support Plan for 10,000 Postdoctoral Fellows" in Wikipedia states that "around 1994, it began to be described in the mainstream media as a relief measure to hire the overabundance of postdoctoral fellows." Although no references or other evidence are provided here, and the content is not fully verifiable, this statement itself, which appears in a widely referenced medium, is considered to be a typical example of how the general public perceived the plan.

for research personnel, especially the difficulty in finding employment for PhD holders, is observed in many developed countries, and thus Japan is not unique in this respect (Kobayashi 2011). One of the unique characteristics of the Japanese situation is the lack of a growing need in society for doctoral degree holders. Comparing the number of doctoral degree holders per population, Japan's value is smaller than that of the U.S., U.K., Germany, Korea, or France, and only Japan has shown a declining trend over the past decade or more.13 In major industrialized countries where the number of doctoral degree holders per population is higher than in Japan, and especially in countries where it is increasing, the need for highly specialized human resources for innovation, economic growth, or solving social issues is increasing, as is the need for research personnel, including those with doctoral degrees. The situation in those countries also differs significantly from that in Japan in that overall national investment in universities is increasing.

Another aspect of Japan's uniqueness is that while human resource development has long been regarded as an important issue at the highest level of science and technology policy, in many cases the "vision of human resources" on which such discussions are based has remained within the framework of academic "researchers" and has rarely been viewed within the broader framework of human resources who are responsible for innovation.14 For example, the process followed by Japanese policy discussions to diversify career paths for doctoral graduates after the "post-doctoral problem" emerged may be related to the fact that "researchers" were the model for policy discussions.

The uniqueness of the Japanese situation described above is not based on fully analyzed results, as there are very few studies on international comparisons on this issue, and further research needs to be conducted; survey results that provide a clue to this issue will be introduced below. The European Commission and OECD have recently published the results of a study on key national policy issues related to human resources for science, technology, and innovation (European Commission and OECD 2019). The results show that most of the 56 responding countries or regions emphasize the importance of strengthening human resources to enhance their country's ability for innovation, but only approximately one-third of the countries or regions also consider measures related to doctoral students, post-doctoral fellows, early career researchers, or improving the attractiveness and status of the research workforce to be important

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13 In 2019, the number of doctoral degrees per each million of the population was as follows: U. S. (579), U. K. (361), Germany (345), South Korea (296), and France (167); Japan (120) was below those countries. In the 20 years since 2000, this figure has more than doubled in the U.S., U.K., and South Korea, and remained almost flat in Germany and France, although it has remained higher than in Japan. Japan peaked in 2006 and has been on a downward trend since then (National Institute of Science and Technology Policy, Ministry of Education, Culture, Sports, Science and Technology, 2022).

14 Kobayashi (2004b), as mentioned in footnote 5, points out that "in Japan, the argument is that science and technology personnel = researchers." Furthermore, Kobayashi (2011), after depicting the situation in other countries and the characteristics of Japan in recent years regarding human resource issues in science and technology policy, states that "compared to Europe and the U.S., Japan has not emphasized innovation in its human resource policies. Therefore, there are some differences between Western countries and Japan in their approach to human resource issues." He also points out that "over the past decade, there has certainly been a significant difference in policy issues and thinking between Europe and the United States, where innovation-oriented human resource policies are emphasized, and Japan, where there has been no comprehensive discussion of human resource policies from the same perspective."

policy issues. Additionally, there are few countries like Japan where these issues are at the top level in the area of science, technology, and innovation policy.

3-3. Issues Surrounding the Doctoral Personnel in Industry

The lack of hiring doctoral degree holders in industry is often discussed as part of the problem of the difficulty in finding employment for doctoral degree holders, but it is also a separate issue related to the utilization of highly specialized human resources in industry. The number of doctoral degree holders per capita in Japan is low for a developed country, and for many years, Japanese companies have employed master's and bachelor's degree holders as the core of their workforce and provided them with the necessary education in-house, rather than hiring doctoral degree holders. However, in developed and other semi-developed countries, particularly in Europe and the U.S., there has been a marked increase in the number of doctoral graduates employed in industry since the turn of the century, a situation that contrasts sharply with that of Japan.

The problem of doctoral degree holders not being active in industry in Japan has often been discussed as a problem on the part of the universities that train them. For example, Japanese doctoral degree holders are criticized for being confined to their own specialized fields and having narrow perspectives, or for lacking the flexibility to tackle diverse issues (Kobayashi 2010). However, there is also criticism that the problem lies with companies that do not treat doctoral degree holders appropriately and do not utilize them well.[15] In particular, there is a view that the human resource system based on lifetime employment and seniority, which has been the mainstream in Japanese companies for many years, is unsuitable for the employment of doctoral degree holders, and it is possible that the spread of job-based employment may promote the employment of doctoral degree holders in the future (METI/Fujitsu Research Institute Ltd. 2021, METI/Deloitte Touche Tohmatsu LLC 2022). A more fundamental problem is the lack of appropriate interaction between the human resource development functions of universities and the human resource needs of society and industry at the macro level (Kobayashi 2004b, METI 2022).

3-4. Mobility of Human Resources in Science and Technology, International Mobility of Highly Skilled Human Resources, and "Competition for Talent"

Many have pointed out or argued that human resources in science and technology are "human capital" that embodies knowledge, experience, and skills in science and technology, and that their mobility is closely related to innovation

15 Hamanaka (2013) states that the "theory that graduate school is the cause," which proposes that the content of graduate school education is the cause of employment difficulties for those who have graduated from graduate school, "can be said to be a common theory." Furthermore, based on analysis of interview survey data from graduate school graduates and corporate HR personnel, "the 'theory that corporations are the cause' can also be proposed."

(OECD 2001a, OECD 2001b, Pogue 2007). Mobility here can either be intra or inter-organizational, between departments and sectors both domestically and internationally. The reasons why the movement of human resources in science and technology promotes innovation include the fact that the movement of human resources leads to the combination of different knowledge and progress in the utilization of knowledge, but it is difficult to quantify the mechanism and promoting effect, and there is no clear empirical basis for this. In Japan, because lifetime employment is the norm, labor mobility among workers in general is extremely low, as is the mobility of human resources in science and technology, of which they are a part; mobility of research personnel belonging to universities and public research institutions is also low. For this reason, the promotion of human resource mobility is often mentioned as an important issue in government policy documents, including the Science and Technology Basic Plan.

In this mobility of human resources, international mobility is actively discussed and as an important theme in science and technology innovation policy worldwide,[16] and is also actively analyzed in science, technology, and innovation policy research. This is due to the rapid progress of globalization since the end of the Cold War, and also influenced by the view that in some parts of the world, there is a situation that can be described as a competition for human resources with highly specialized and advanced knowledge, such as doctoral degree holders (Murakami 2008). Note that the human resources under discussion are often referred to as "highly skilled human resources" (OECD 2001b) worldwide, as mentioned in 2-2(4).

In Japan, to promote the acceptance of highly skilled human resources from abroad, a system was introduced in 2012 to establish a "highly skilled professional" status of residence and to provide preferential treatment in terms of immigration control and residency management. Under this system, the activities of high-level foreign human resources are classified into three categories: "advanced academic research activities," "advanced specialized/technical activities," and "advanced business management activities." A "highly skilled human resource point system" has been introduced, in which, according to the characteristics of each category, academic background, work experience, and annual income are scored to determine the "highly skilled professional" status of residence.

Moreover, the Immigration Control and Refugee Recognition Act stipulates three types of "specified activities" under the status of residence: (1) specified research activities (activities to engage in research, guidance of research, and education related to a specific field at a research institution), (2) specified information processing activities (activities to engage in work related to information processing requiring technology or knowledge in the field of natural science or humanities), and (3) dependent activities related to those engaged in specified research and dependent

16 According to a survey by the European Commission and OECD, the most frequent theme in policy discussions on human resources for research and innovation in OECD and European Union member countries is the "international mobility of human resources." (European Commission and OECD 2021)

activities related to those engaged in specified information processing (activities conducted in Japan by a dependent spouse or child of a foreign national staying in Japan under (1) or (2) above).

3-5 Other Policy Discussions Related to Human Resources

In the policy issues described thus far, there has been much discussion about institutions of higher education such as universities, but policies related to the development of human resources for science, technology, and innovation will include not only higher education but also primary and secondary education. This is the case in many countries around the world and is thought to be due to the recognition that the development of human resources for science, technology, and innovation will lead to economic growth and enhanced competitiveness, and that science and technology-related education from an early stage is important for this purpose. In Japan, policies have long been implemented to link primary and secondary education to the development of human resources for science, technology, and innovation, but the trend is strengthening even more.[17] Recently, in elementary and secondary education, “Art” has been added to “STEM” mentioned in 2-2 (4) to create the acronym “STEAM” (Science, Technology, Engineering, Art, and Mathematics), a word that refers to a wide range of areas including arts, culture, life, economy, law, politics, and ethics; the promotion of STEAM education is being implemented. The 6th Science, Technology, and Innovation Plan (2021–2025) includes a description of “promotion of STEAM education,” and the term is now used in policy discussions on science, technology, and innovation policy.

Another term that has been increasingly used in discussions of science, technology, and innovation policy is “recurrent education.”[18] “Recurrent education” is a similar concept to “lifelong learning,” but it focuses more on the nature of learning knowledge and skills to apply to work than the latter.[19] “Recurrent education” has come to be discussed in the context of science, technology, and innovation policy because of the rapid progress and change in science and technology, the rapid obsolescence of expertise, and the need to update the expertise and skills of specialists who are already active in society.[20] Moreover, it is becoming increasingly difficult to respond to the conventional model

17 All the Basic Plans from the 1st Science and Technology Basic Plan (1996–2000) to the 6th Science, Technology, and Innovation Plan (2021–2025) contain descriptions of policies on “elementary and secondary education.” The frequency of use of the term “elementary and secondary education” in these basic plans tends to increase with newer plans. (Based on the results using “Science and Technology Basic Policy Document Search” <https://www.nistep.go.jp/research-scisip-whitepaper-search> published by the National Institute of Science and Technology Policy).

18 The term “recurrent education” is used in six places in the 6th Science, Technology, and Innovation Plan.

19 On “recurrent education” and “lifelong learning,” the Public Relations Office of the Government of Japan website (August 2021) states that “both are the same in terms of ‘learning,’ but the purpose of learning is different. Recurrent education teaches knowledge and skills to be applied on the job. …In contrast, lifelong learning is any kind of learning that takes place over the course of a lifetime, and includes schooling, social education, as well as cultural activities, sports, volunteer activities, hobbies, and other activities unrelated to work or that lead to a ‘purpose in life’.”

20 Morozumi, Saito, and Kobayashi (2004) show the obsolescence of expertise and skills by analyzing changes over time in employment information and qualifications for information professionals. Nakanishi and Yamada (2010) and other studies measured the obsolescence rate of scientific and technological knowledge using patent data, although not analyses related to human resources, and the references in the same paper provide representative examples of such measurements, including English references.

of human resource development in science and technology, in which graduates who have acquired specialized scientific and technological knowledge at institutions of higher education are active in society, and it could also be seen as a means of strengthening the human resource development system itself. Furthermore, this type of education is expected to help engineers in various fields learn the latest information technology, which will lead to innovation.

Although different in nature from the above, the promotion of human resource diversity (diversity) has rapidly become a focus of science, technology, and innovation policy in recent years. Originally, in Japan, social and labor policies have focused on the promotion of women's employment and participation in society, but with the enactment of the Law for the Equal Employment Opportunity for Men and Women (popularized name) in 1985 and the Basic Law for a Gender-Equal Society (1999), the promotion of female researchers' activities has gradually increased in the area of science, technology, and innovation policy. However, it is only more recently that policies such as the quantitative increase of female researchers have been raised in terms of strengthening human resources for science, technology, and innovation. For example, in the 3rd Science and Technology Basic Plan (2006–2010), a numerical target of 25% was set for the ratio of female researchers employed at universities and public research institutions in the natural sciences. Recently, based on the globally accepted idea that expanding the diversity of human resources leads to innovation, the promotion of the employment and active roles of women and non-Japanese people has become an important policy issue, and the 6th Science, Technology, and Innovation Plan also uses the keyword "diversity" when discussing human resources.

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Related Data Sources

Human Resources in Science and Technology

In Japan, although general statistical data based on the Canberra Manual are not collected, the Basic School Survey (MEXT), a basic educational statistic, provides an annual survey on the number of university graduates, with a breakdown by department and type of organization where they are employed. This corresponds to the "HRST Inflow" in the Canberra Manual, which is considered a new human resource to be added to HRST.

- https://www.mext.go.jp/b_menu/toukei/main_b8.htm

The total number of "scientific researchers" and "engineers" is also surveyed in the national census (demographic survey). However, it is not based on international definitions. There is also a considerable difference between the definition of "scientific researcher" here and the definition of "researcher" given in 2-2(2).

- https://www.stat.go.jp/data/kokusei/2020/index.html

R&D Personnel

Data on R&D personnel in each sector (industry, higher education, government, and private non-profit) are collected annually through the "Survey of Science and Technology Research," of the Statistics Bureau, Ministry of Internal Affairs and Communications, which is the basic R&D statistic in Japan. This is essentially in accordance with the Frascati Manual.

- https://www.stat.go.jp/data/kagaku/index.html

In addition to the above, detailed data on researchers (university faculty and graduate students) affiliated with institutions of higher education are compiled annually using the "Basic School Survey" (MEXT). Furthermore, the "Statistical Survey of School Teachers" is conducted every three years for university teachers.

- https://www.mext.go.jp/b_menu/toukei/main_b8.htm

Doctoral Degree Holders

The National Institute of Science and Technology Policy (NISTEP) of the Ministry of Education, Culture, Sports, Science and Technology (MEXT) is currently developing a "Doctoral Human Resources Database (JGRAD)" to survey the activities of doctoral degree holders in society. The 52 universities participating in this project (as of April 2022) provide NISTEP with the initial registration information of the doctoral students, and after the initial registration, the registrant continuously inputs career and other information into JGRAD after completing the doctoral program.

- https://jgrad.nistep.go.jp/about/about_jgrad.html

In parallel, NISTEP has been conducting the Japan Doctoral Human Resource Profiling (JDPRO) project for those who have completed graduate school doctoral programs.

・https://www.nistep.go.jp/jdpro/

International Mobility of Human Resources in Science and Technology

Human resources in science and technology outflows and inflows from the country are not in line with international standards, but the following data sources are available.

The "Immigration Statistics" of the Immigration Bureau of Japan surveys the number of incoming and outgoing foreigners by status of residence and nationality/region, and data on the number of incoming and outgoing foreigners, including the "highly specialized professionals" mentioned in 3-4, are available. Moreover, the "Statistics on Foreign Residents" of the Immigration Bureau of Japan of the Ministry of Justice produces statistical data on foreign residents by status of residence (purpose of residence), and data on the number of foreign residents whose purpose of residence is "research" or "highly specialized professional" as described in 3-3 are available.

・https://www.moj.go.jp/isa/policies/statistics/index.html