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Asia and Pacific Research Center

Research on the Nurturing and Maintaining of STI Talent in Singapore

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Japan Science and Technology Agency

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This report is compiled as part of a research that surveyed and analyzed science and technology innovation policies, research and development trends, and associated economic and social circumstances in the Asia-Pacific region. It is being made public on the APRC website and portal site to enable wide use by policymakers, associated researchers, and people with a strong interest in collaborating with the Asia-Pacific region; please see the websites below for more details.

APRC website:
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Executive Summary

The Asia and Pacific region is currently, in terms of rapid economic growth, one of the most remarkable in the world. It has also achieved innovative progress in science and technology over the most recent decade. Singapore, in particular, has attracted high attention from the global R&D community due to its science and technology output, such as the ESI Top Papers.

This report aims to clarify Singapore's policies and strategies on the nurturing and maintaining talent in the field of science and technology and suggests possible implications for Japan's scientific and technological prosperity. The report first covers basic STI indicators and policies along with the necessary social background. Second, it shows the following main relevant policies: (1) nurturing domestic STI talent in Singapore; (2) promoting STI talent to study abroad; (3) inviting Singaporean STI talent to return home; (4) supporting foreign students; (5) other relevant policies which include employment and education. It also focuses on inviting foreign students to Singapore since they are expected to contribute as human resources in R&D into the future. It supplementally covers educational and labor market policy in relevant fields. The former includes institutional change in early 2000s as a response to the new societal needs for more innovative and creative talent, and the latter includes recent employment transferring strategies in reaction to the recent shift to knowledge-intensive economy and ICT industry.

The characteristics of Singapore's STI sector are summarized as follows: (1) A high ratio of foreign researchers, and a strong tendency to not differentiate between nationality when providing scholarship and fellowship; (2) A high ratio of female researchers and strong tendency of non-differentiation in gender for recruitment and promotion; (3) High mobility of STI talent, taking full advantage of foreign manpower for its internal development; (4) The National University of Singapore, the top university in the country, is strongly oriented toward collaboration with industry and has maintained the top position in the Asia-Pacific region since 2018 in various world university rankings.

Lessons that Japan can take from this are summarized as follows: (1) Increase public and private funding for R&D activity in a sustainable manner; (2) Take measures to reduce systemic differentiation between nationalities amid the global race for talent; (3) Avoid overly defensive measures against technology leakage to maintain a free and open research environment; (4) flexibly nurture potential talent in science and technology, actively call for the return of excellent foreign-based Japanese nationals and promote the recruitment of foreign and female researchers.

Singapore's success is often symbolized by Biopolis, which was established immediately after the founding of the Agency for Science, Technology and Research (A*STAR). However, as indicated in the recommendations above, various human resource development measures are creating a synergistic effect in Singapore. Bold educational reforms and flexible employment transition measures in response to social needs and changes in industry are thought to have secured scientific and technological human resources with a rich diversity of nationality, gender, and age.

Based on the practices seen in Singapore, the authors believe that Japan can enhance the development and retention of its STI talent and lead to further development of science and technology by steadily increasing investment in R&D and striving to create a diverse research environment that reduces the loss of domestic human resources.

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1 Report Overview

1.1 Background and Purpose of this Report

The Asia-Pacific region (the "Asia-Pacific region" refers to the region that includes both Asia and Oceania as listed in the Cabinet Order for Organization of the Ministry of Foreign Affairs) accounts for approximately 60% of the world's population, as well as nearly 30% to 40% of the global GDP and R&D expenditures, and has come to have a major impact on global politics, economy, and society. Particularly, in terms of the economy, the region's share[1] of the global (nominal) GDP was 34.4% in 2021, up from 18.8% in 1980, 40 years ago, and from 25.5% in 2000, 20 years ago, which are rapid increases of approximately 80% and 30%, respectively. The Asia-Pacific region is driving the world economy as the world's growth center.

This rapid development in the Asia-Pacific region can be attributed largely to the steady progress made in nurturing and securing the scientific and technological human resources that provide the foundation for research and development (R&D) activities for the economic activities and growth of the countries and territories in the region. Strengthening measures to nurture and maintain science and technology human resources is a policy that is almost common in these regions. Particularly in China (whose share of global GDP has increased by approximately seven times in 40 years) as well as in South Korea and Singapore (whose share of global GDP has increased by three to four times in 40 years), which are among the fastest developing countries in the region, the following policies have been implemented: (1) Strengthening domestic nurturing of highly skilled human resources by promoting domestic higher education institutions, (2) Strengthening the training of students and researchers from their own country as well as of international students from overseas, and (3) while doing (1) and (2), attracting excellent human resources from overseas, including their own citizens. It can be said that the development of these countries would not have been possible without investments in nurturing and securing science and technology human resources and the implementation of effective measures.

Japan's share of the global GDP has been stagnant for a long period of time; in terms of science and technology, its global share of the total number of papers and of the number of highly cited papers has been declining in recent years; and, in particular, in order to nurture and maintain research human resources in Japan, it is essential to elucidate, understand, and refer to the situation in the aforementioned rapidly developing major countries in the Asia-Pacific region for nurturing and securing such scientific and technological human resources.

In promoting science and technology cooperation with these countries, it is considered effective to understand what kind of measures they are taking to nurture and maintain human resources in order to promote smooth and strong cooperation.

Based on the above, a survey on nurturing and securing human resources for science and technology in the Asia-Pacific region was conducted for the following purposes.

① From the perspective of maintaining and improving Japan's research capabilities, understand the policies and strategies of major countries in the Asia-Pacific region regarding nurturing and securing human resources

[1] Based on lecture materials at the 18th Asia-Pacific Research Conference, "Asia and Japan in a Time of Global Transition" (held on January 19, 2023; Lecturer: Takashi Shiraishi). https://spap.jst.go.jp/event/apstudy018.html

for science and technology, and identify matters that should be referred to in promoting nurturing and maintenance science and technology human resources in Japan.

② Understand the policies and strategies of major countries in the Asia-Pacific region for nurturing and securing human resources for science and technology, and provide basic information for promoting science and technology cooperation between Japan and major countries in the Asia-Pacific region.

1.2 Reasons for Selecting the Survey Country (Singapore)

Singapore was selected for this report for the following reasons.

First, Singapore has achieved remarkable economic development in recent years (its GDP as a percentage of the world's total GDP has increased by 4x in 40 years).[2] Second, the quality of scientific publications in Singapore is higher than in other Asia-Pacific countries and regions.

In addition to these reasons, Singapore, as an innovation hub in the Asia-Pacific region, is focusing on nurturing homegrown startups, promoting entrepreneurship, and accepting top scientific and technological talent from around the world. Furthermore, Singapore's geographical location on the border between the English-speaking and Chinese-speaking worlds has enabled it to accept human resources from both the US and China for its own development.[3] Looking back at the history of research and development, in the early 1990s Singapore focused on medical and life sciences, and in recent years it has concentrated on the field of information science, particularly in the areas of computing and artificial intelligence (AI), and has taken measures to nurture and maintain the human resources required in each field.

Based on the above, it is believed that Singapore's policies and strategies for nurturing and securing outstanding human resources have a wealth of implications for Japan in adapting to the development of science and technology and the accompanying changes in industrial structure.

1.3 Survey Method and Summary

From the aforementioned perspectives, this report investigates the various data, policies, and measures, etc. related to nurturing and securing science and technology human resources in Singapore. From the perspective of cultivating and strengthening Japan's scientific and technological capabilities, particularly its scientific capabilities, the science and technology human resources who were surveyed for this report were primarily researchers (those who have completed a graduate school course and are engaged in specialized activities based on their course of study in that subject, and included students in master's programs or higher). However, as necessary, the survey also includes human resources who support overall science and technology activities in general, as well as the students and international students who form the basis of these activities. However, with regards to international students, in view of the reliability of data acquisition in Singapore, this report is focused on measures to attract international students.

2 Same as footnote 1.

3 The following article, for example, is typical of Singapore's perception of its position as being in between the two countries, benefiting from the ongoing friction between the U.S. and China since the 2010s, and seeking an appropriate way of standing in between the two countries. ("Singapore wields its neutrality to attract Chinese Talent," Nikkei Asia, September 2, 2022.)

This report clarifies the following topics:

First, an overview of Singapore's research capabilities will be looked at in order to obtain a general picture of the state of science and technology in the country. In order to understand not only the numerical values for the "number of researchers," "number of papers, number of highly cited papers, and proportion of internationally co-authored papers," and "number of patents," etc., but also Singapore's international position, this report will utilize country-by-country rankings or comparisons with other countries.

Next, Singapore's basic policies and major measures for nurturing science and technology human resources will be clarified.

The primary content of these basic policies for nurturing and securing science and technology human resources are described from policy documents and the latest policy statements, and background information is introduced and provided as necessary.

Singapore's primary measures for developing science and technology human resources are presented in the following categories: (1) Nurturing researchers within Singapore, (2) nurturing researchers overseas, (3) inviting international researchers, (4) supporting international students, and (5) other notable measures for nurturing science and technology human resources.

Furthermore, as a development that is adjacent to nurturing and securing researchers, this report also conducted supplementary research on education policy and labor market policy. The former focuses on institutional reforms at the beginning of the 21st century (particularly those related to science education), while the latter looks at strategies to expand the employment of digital human resources that reflect recent science and technology trends and industrial structural changes, especially digital transformation (DX).

Based on the above survey results, and taking into consideration the position of science and technology in Singapore's industrial structure and economy, this report presents an evaluation of and the characteristics of the country's nurturing and securing of science and technology human resources, as well as points that Japan should refer to.

In compiling this report, consideration was given to Japan's general situation surrounding and issues related to nurturing and securing science and technology human resources, as shown in 1.4 below.

1.4 Overview of and Challenges Related to Nurturing and Maintaining Science and Technology Human Resources in Japan, and Special Considerations in Surveys of Major Countries

In order to effectively conduct the survey and to make recommendations on what Japan should refer to, from the perspective of international science and technology indicators, this report looks at the general situation in Japan for nurturing and securing science and technology human resources and also clarifies the issues involved. International comparisons were made using data from the Japanese Science and Technology Indicators 2022,[4] except where other

[4] "Japanese Science and Technology Indicators 2022," NISTEP Research material No. 318, Ministry of Education, Culture, Sports, Science and Technology, National Institute of Science and Technology Policy.

sources are specifically specified. In addition, issues with nurturing and securing science and technology human resources in Japan were organized based on the 6th Science, Technology and Innovation Basic Plan.[5]

1.4.1 Overview of Nurturing and Maintaining Science and Technology Human Resources in Japan

(1) General discussion

In order to further improve Japan's science and technology capabilities, it is first necessary to look at an overview of Japan's science and technology activities from an international comparative perspective. This section discusses Japan's number of papers and number of highly cited papers, which are the results of science and technology activities, as well as whether these results are commensurate with Japan's R&D expenses and number of researchers, which are investments in science and technology activities.

① Indicator of research capabilities: number of papers and number of highly cited papers

In terms of the number of papers and number of highly cited papers, which are results of science and technology activities and are considered to be indictors of research strength, last year Japan's ranking in the number of papers (fractional count) dropped from 4th place to 5th place, according to Japanese Science and Technology Indicators 2022. Additionally, Japan's ranking in the top 10% for number of revised/corrected papers (fractional count) also fell last year from 10th place to 12th place. Japan's place in both of these rankings and Japan's share of the global total have considerably declined over the past 20 years.

② Indicator of technical capabilities: number of patent applications

In terms of the number of patent applications (patent families), which are results of science and technology activities and are considered to be indicators of technological capabilities, Japan remains in 1st place, the same as last year, and its share of the global total has remained high and virtually unchanged over the past 20 years.

③ R&D expenditures and number of researchers

In terms of R&D expenditures, which represent investment in scientific and technological activities, Japan ranks 3rd, the same as the previous year, but if the focus is only on universities then Japan ranks 4th, also the same as the previous year. Furthermore, in terms of the number of researchers, Japan ranks 3rd, the same as the previous year (if the focus is only on universities then Japan is estimated to be 4th, the same as the previous year[6]).

④ Evaluation

Japan's research strength, as measured by the number of papers and the number of highly cited papers, has been declining over the long term. Given that Japan is currently ranked 3rd in terms of GDP (2021), 3rd in R&D expenditures, and 3rd in the number of researchers, there are major issues that need to be improved. In particular, when it comes to nurturing and securing science and technology human resources, as will be explained later, there is a strong correlation between the number of research papers and the number

[5] The "6th Science, Technology, and Innovation Basic Plan" was approved by the Cabinet Office on March 26, 2021.

[6] The number of researchers for US universities only is not shown in the Japanese Science and Technology Indicators 2022, but, because it is estimated that US universities have more researchers than Japanese universities, this report estimates that, excluding the US, Japan is ranked 4th, one place down from 3rd place.

of researchers at universities, etc., and as such securing and maintaining the number of researchers at universities, etc. is an urgent issue. Additionally, there are concerns that the quality of Japan's research papers will decline due to the decline in Japan's global share of the number of highly cited papers, and, in general, in order to improve quality it is necessary to increase the proportion of the number of internationally co-authored papers, further progress in brain circulation amongst researchers is required. As described later in this report, the proportion of the number of internationally co-authored papers has an extremely strong correlation with the sum of (1) the number of international students as a percentage of the total number of students enrolled in higher education institutions in a country and (2) the number of students who are studying abroad. It is estimated that improved brain circulation not only among researchers but also among students will lead to an increase in the number of internationally co-authored papers, and further promotion is desirable.

On the other hand, Japan's technological capabilities, as measured by the number of patent applications (patent families), has shown excellent results, although normally it is necessary to closely scrutinize the state of technology trade, etc.

(2) Current status of and trends in the number of researchers in Japan

The current status of and trends in number of researchers in Japan are shown below:

- After reaching 670,000 in 2006, the total number of researchers in Japan has remained roughly the same or has been on a slight upward trend.
- In 2021, there were 690,000 researchers in Japan (FTE value), ranking third after China and the United States.
- Since 2000, the number of researchers in other major countries (China, the United States, Germany, Korea, etc.) has been steadily increasing, while the number of researchers in Japan has been decreasing relative to other countries. In particular, the percentage of researchers at universities and R&D institutes, etc., excluding those at companies, is about 25% in Japan, which is the lowest among major countries except South Korea, and the fifth highest among major countries after China, the United States, the United Kingdom, and Germany in terms of the total number of researchers.

As shown in the following table, which is a comparison of research strength (number of research papers) and number of researchers (number of researchers at universities and R&D institutions, excluding corporate researchers) for the top five countries in terms of the number of research papers (China, the United States, the United Kingdom, Germany, and Japan), the international rankings are the same, indicating an extremely strong correlation.

From this, it can be said that securing/maintaining the number of researchers at universities, etc. is an urgent issue.

Table 1-1: Number of papers and number of researchers (universities, etc.) for major countries

Country	Number of papers	Top10% number of papers	Number of researchers [total]	Number of researchers [per capita]	Number of researchers [universities and R&D institutions, etc.]
	Share (rank)	Share (rank)	10,000 researchers (rank)	Researchers per 10,000 people	10,000 researchers (rank)
China	26.8 (1)	33.4 (1)	228.1(1)	29.1	94.7(1)
United States	22.9 (2)	31.8 (2)	158.6(2)	-	43.9(2)
United Kingdom	7.0 (3)	11.4 (3)	31.6(5)	-	18.4(3)
Germany	6.6 (4)	9.0 (4)	45.2(4)	103.8	18.0(4)
Japan	5.0 (5)	4.0 (12)	69.0(3)	98.8	17.5(5)
Singapore	<1.0 (25+)	1.9 (20)	4.6(25+)	104.4	2.2(25+)

Source: NISTEP Japanese Science and Technology Indicators 2022

Note 1: "Number of papers" and "Top 10% number of papers" are 2018 to 2020 values based on integer counts.

Note 2: "Number of researchers [per 10,000 population]" is the "Number of researchers [total]" divided by that country' s population (units: 100,000 people)

Note 3: "Number of researchers [universities and R&D institutions, etc.]" is the number of researchers at other institutions, excluding companies.

Note 4: "Number of researchers [total]", "Number of researchers [per capita]", and "Number of researchers [universities and R&D institutions, etc.]" is 2019 data for the United States and the United Kingdom, 2020 data for China, Germany, and Singapore, and 2021 data for Japan.

(3) Nurturing researchers domestically

As an indicator of domestic nurturing of Japanese researchers, the number of doctoral degree holders and the number of new doctoral degree holders are shown below.

- The number of Japanese researchers holding doctoral degrees was 182,000 in 2021, about a quarter of the total number of researchers. Of these, most (157,000) are affiliated with universities and R&D institutes, excluding companies.
- The number of new doctoral degree recipients in Japan has remained flat since FY2000, reaching 15,000 in FY2019. Internationally, in FY2019 Japan had fewer new doctoral degree recipients than the United States (92,000; FY2018 data), China (61,000), Germany (29,000), the United Kingdom (24,000) and South Korea (15,000), but more than France, so Japan is at a low level internationally. On the other hand, compared to FY2000, the number of new doctoral degree recipients has almost doubled in South Korea, China, the United States, and the United Kingdom, but has remained almost flat in Japan, Germany, and France.

In light of the above, increasing the number of new doctoral degree holders in Japan is an urgent issue.

(4) Nurturing researchers overseas

As an indicator of the overseas nurturing of Japanese researchers, international mobility as seen in the number of overseas students in Japan, the number of Japanese-born doctoral degree holders in the United States, and the institutions to which Japanese researchers belonged when writing scientific papers are shown below.

- The number of overseas students in Japan[7] was 107,000 in FY2019, when the impact of the COVID-19 pandemic was minimal, and has increased by approximately three times since FY2009.
- On the other hand, the number of Japanese-born doctoral degree holders in the United States[8] was 114 in 2020 (129 in 2019). This figure was 236 in 2010, and, over the intervening 10 years, while the number of non-US-born doctoral degree holders in the United States increased (from 13,636 to 18,482) the number of Japanese-born doctoral degree holders in the United States was roughly halved (down 52%), which is the largest rate of decline amongst major countries.
- The international mobility of Japanese researchers (authors of scientific papers) [9] is extremely low when compared to other countries, especially when compared to Europe and the United States, and Japan's numbers per researcher and per GDP are on the same level as those of China and South Korea.

Based on the above, and from the perspective of increasing the number of internationally co-authored papers and of improving the quality of research and research papers, Japan requires further promotion of brain circulation amongst researchers in addition to supporting human resources who obtain degrees (doctoral degrees, etc.) overseas.

(5) Inviting international researchers

The number of international researchers that Japan accepts from abroad is shown below.

- The number of researchers that Japan accepted from abroad[10] was 35,228 in 2019 (of which, 21,948 were researchers with a short-term stay of less than one month, slightly less than the previous year due to the effects of the COVID-19 pandemic, and 13,280 researchers who with medium- to long-term stays of one month or more). Japan's acceptance of researchers on both short-term and medium- to long-term stays have been flat since around 2000.

Considering that steadily increasing the number of outstanding international researchers invited to Japan will not only lead to the development of joint research, etc. when the researchers are accepted, but also to long-term stays and permanent residence for outstanding researchers, improving the environment for accepting researchers, including for their families, is an issue that should be addressed on an ongoing basis.

(6) Supporting international students

The number of international students in Japan[11] is shown below.

- The number of international students in Japan (including international students enrolled in "Japanese language education institutions" in addition to "higher education institutions") was 312,000 in 2019, when the impact of the COVID-19 pandemic was minimal. This number has more than doubled from the 132,000 in 2009 (the data at this point does not include international students enrolled in "Japanese language education institutions").

7 "Survey of Japanese Students Studying Abroad in Japan in FY2019," Japan Student Services Organization, March 2021

8 "Science and Engineering Indicators, Survey of Earned Doctorates," NSF

9 "Promoting International Brain Circulation," Science and Technology Policy Bureau, Counselor (International Strategy), June 9, 2021.

10 "Strategies for the International Expansion of Science and Technology," Council for Science and Technology, International Strategy Committee, March 30, 2020.

11 "FY2021 International Student Enrollment Survey Results," Japan Student Services Organization, March 2022

• In FY2020 and FY2021, almost no international students, with the exception of some government-sponsored international students, were allowed to enter Japan because of strengthened immigration control measures due to the COVID-19 pandemic, and as a result the number of international students declined for two consecutive years, to 280,000 and 242,000, respectively.

As shown in the following table, the international ranking of the sum of (1) number of international students as a percentage of total enrollment in higher education institutions in major countries and (2) the percentage of a country's students who are studying abroad shows that there is an extremely strong correlation with the international ranking of the ratio for the number of internationally co-authored papers. Although there are a variety of factors that determine the ratio for the number of internationally co-authored papers, it can be assumed that increasing the international mobility of students is effective in increasing ratio of the number of internationally co-authored papers, and, in order to improve Japan's research capabilities, it is important not just to secure Japanese students who are studying abroad, but also to secure international students who are studying in Japan.

Table 1-2: Student mobility indicators and ratio for the number of internationally co-authored papers (2019)

Country	Ratio of international students (A, %)	Ratio of the country's students studying abroad (B, %)	Total international students for the country (C, %)	D (%)
United Kingdom	19	2	21	71
France	9	4	13	66
Germany	10	4	14	62
United States	5	1	6	47
Japan	5	1	6	36
South Korea	3	3	6	32
China	0	2	2	26

Source: OECD Education at a Glance 2021

A: Ratio of the number of international students to the number of students enrolled in higher education institutions in the country
B: Ratio of international students who are enrolled in overseas higher education institutions
C: Total international students for the country (sum of A + B)
D: Ratio for the number of internationally co-authored papers

(7) Nurturing and maintaining female researchers

In 2021, the proportion of female researchers in Japan was 17.5%.[12] This proportion is the lowest among the OECD countries and regions surveyed in the data cited in the source. The proportion of female researchers in major countries, such as those in Europe, is generally between just under 30% to 40%, followed by countries in Asia such as Taiwan at 22.0% (2020 data), South Korea at 21.4% (2020 data), and then Japan. Approximately 10 years

[12] "Japanese Science and Technology Indicators 2022," NISTEP Research material No. 318, Ministry of Education, Culture, Sports, Science and Technology, National Institute of Science and Technology Policy.
Sources: <Japan> Ministry of Internal Affairs and Communications, "Science and Technology Research Survey Report"
<Other countries> OECD< "Main Science and Technology Indicators March 2022"

ago, around 2010, the proportion of female researchers in major countries,[13] such as those in Europe, was generally between 25% and 50%, followed by Taiwan at 20.5% (2009 data), South Korea at 15.8% (2009 data) and then Japan at 13.8% (2011 data). Over the past decade, the composition of the proportion of female researchers has remained unchanged, with the three Asian countries at the bottom and Japan being the lowest, but the three Asian countries have steadily increased their proportion.

From the above, there is considerable room to increase the proportion and number of female researchers in Japan, and the challenge is to strengthen efforts to nurture and maintain female researchers.

1.4.2 Issues in Nurturing and Maintaining Science and Technology Human Resources in Japan

The 6th Science, Technology and Innovation Basic Plan[14] (hereinafter referred to as the "6th Basic Plan" in this section) sets out the following issues in terms of Japan's nurturing and securing science and technology human resources.

The 6th Basic Plan sets three major goals to realize Society 5.0, but, from the perspective of nurturing and securing scientific and technological human resources, especially researchers, it identifies the following two major goals:

(1) Continue to create knowledge with diversity and excellence, and restore the world's highest level of research capabilities

(2) To transform Japan as a whole into Society 5.0, we will develop human resources who will pursue happiness and face challenges

For these major goals, specific initiatives (only items listed here) are given for the following issues from the perspective of nurturing and securing researchers.

(1) Restore the world's highest level of research capabilities

① Rebuilding the environment to produce diverse and outstanding research

- Improving treatment of doctoral students and expanding career paths
- Development of an environment in which young researchers can play active roles in universities
- Promotion of active participation of female researchers
- Promotion of basic and academic research
- Promotion of international joint research and international brain circulation
- Maintaining research time
- Promotion of the humanities and social sciences and creation of the convergence of knowledge
- Integrated reform of the competitive research funding system

[13] "Japanese Science and Technology Indicators 2012," NISTEP Research material No. 214, Ministry of Education, Culture, Sports, Science and Technology, National Institute of Science and Technology Policy.
Sources: <Japan> Ministry of Internal Affairs and Communications, "Science and Technology Research Survey Report"
<Other countries> OECD< "Main Science and Technology Indicators 2011/12"

[14] Same as footnote 4.

② Promoting university reform and expanding functions for strategic management

- Transformation of national university corporations into a true management entity
- Deregulation to support strategic management
- Establishment of a 10 trillion yen university fund
- Diversification of public funds and governance that support the foundations of universities
- Strengthening the functional and financial foundations of national research and development agencies

(2) Foster human resources to transform Japan into Society 5.0

- Strengthening the ability to explore by promoting STEAM education
- Participation and utilization of external human resources in learning
- Promotion of human resource mobility and reinforcement of learning for career change and career advancement
- Provision of diverse curricula and programs at universities and national institutes of technology

Section 1.3.1 indicated the challenges in nurturing and developing Japan's science and technology human resources by comparing data on Japan's science and technology capabilities with those of other major countries, and all of these issues are encompassed in the challenges and concrete measures shown in the 6th Basic Plan above.

The information presented above presents an overview of the situation and challenges in nurturing and securing science and technology human resources in Japan by comparing data on Japan's science and technology capabilities with those of other major countries, and listed the major goals and specific initiatives in the 6th Basic Plan, which is Japan's basic policy for science and technology. In addition to clarifying the evaluation and characteristics of how Singapore fosters and secures science and technology human resources, in light of Japan's situation as described above, this report looks at and introduces items that may be helpful for Japan's challenges and specific initiatives.

2 Overview of Singapore's R&D Capabilities

This section first provides an overview of Singapore's R&D capabilities from the perspective of major science and technology indicators in order to investigate and analyze how Singapore fosters and secures science and technology human resources. In order, this section looks at the inputs for Singapore's R&D capabilities – the human resources and R&D expenditures – and then looks at the outputs for Singapore's R&D capabilities – the paper publications, patent applications/registrations, and research institution rankings.

2.1 Total Population / Numbers of Researchers / Numbers of Research Supporters

Singapore has a total population of approximately 5.67 million people (equivalent to Fukuoka Prefecture in Japan) and a land area of 720 km^2 (equivalent to the 23 wards of Tokyo in Japan),[15] and has also been called a city-state. Looking at its overall population trends (Figure 2-1), the number of citizens and permanent residents has remained at around 4 million for the past five years, with non-residents accounting for about 30% of the population. The number of non-residents slightly decreased in 2021, but increased again in 2022, the most recent year, presumably because the inflow of non-residents decreased in 2021 because of the impacts of the COVID-19 pandemic.

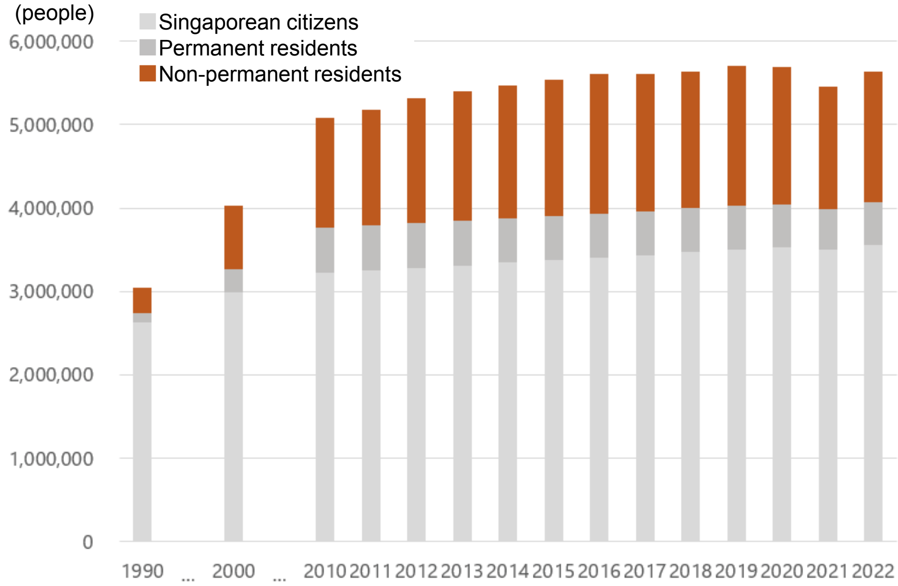

Figure 2-1: Total population of Singapore by residence status (as of the end of 2022)
Note: "Permanent residents" refers to "foreign nationals who have obtained permanent resident status."
Source: Singapore Department of Statistics (SingStat)

Next, the number of researchers rapidly increased from approximately 5,000 in 1990 to approximately 28,000 in 2010, and has steadily increased since 2010, reaching approximately 39,000 in 2020 (Figure 2-2). Furthermore, looking at the change in the number of researchers by residence status over time, the proportion of international researchers to the total number of researchers was approximately 30% in 2020, a significant increase from 25%

[15] Based on basic data from the Ministry of Foreign Affairs. https://www.mofa.go.jp/mofaj/area/singapore/data.html

in 2010. While this proportion is extremely high internationally, it is almost the same as the proportion of non-residents in the total population shown in Figure 2-1.

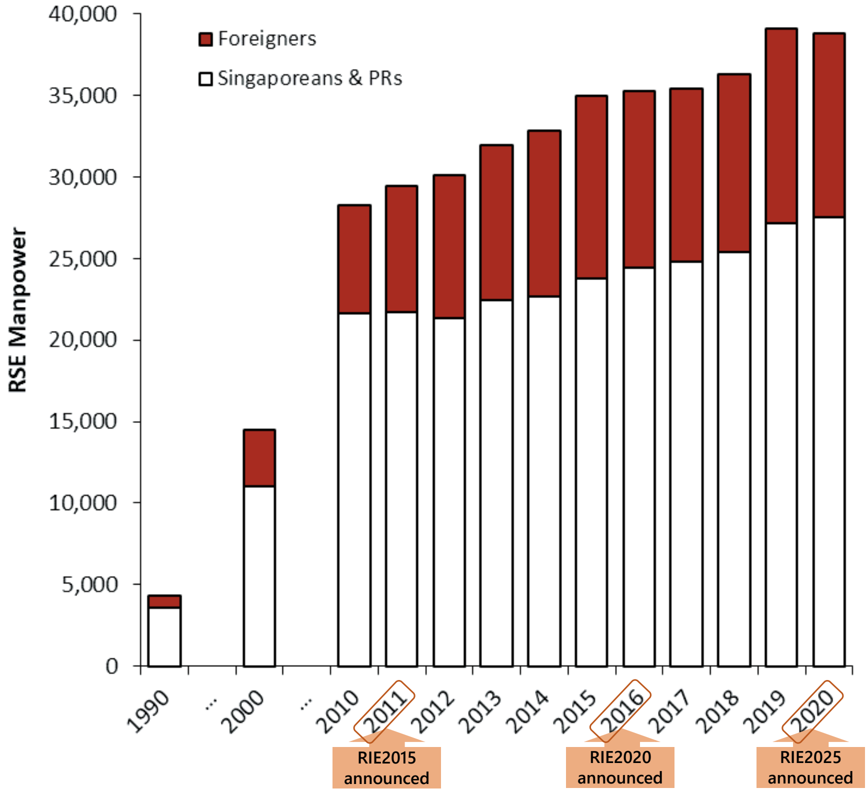

Figure 2-2: Number of researchers by resident status (1990 to 2020)

Source: National Survey of Research, Innovation and Enterprise (RIE) 2020

To understand the level of expertise in Singapore, the distribution of degrees and the number of researchers per academic field was looked at (Figure 2-3). Doctoral students and postdoctoral fellows accounted for the highest percentage in Life Sciences/Medicine and the lowest in Engineering/Technology. The percentage of master's degree students was the highest in Engineering/Technology, while the percentage is similar in the other fields.

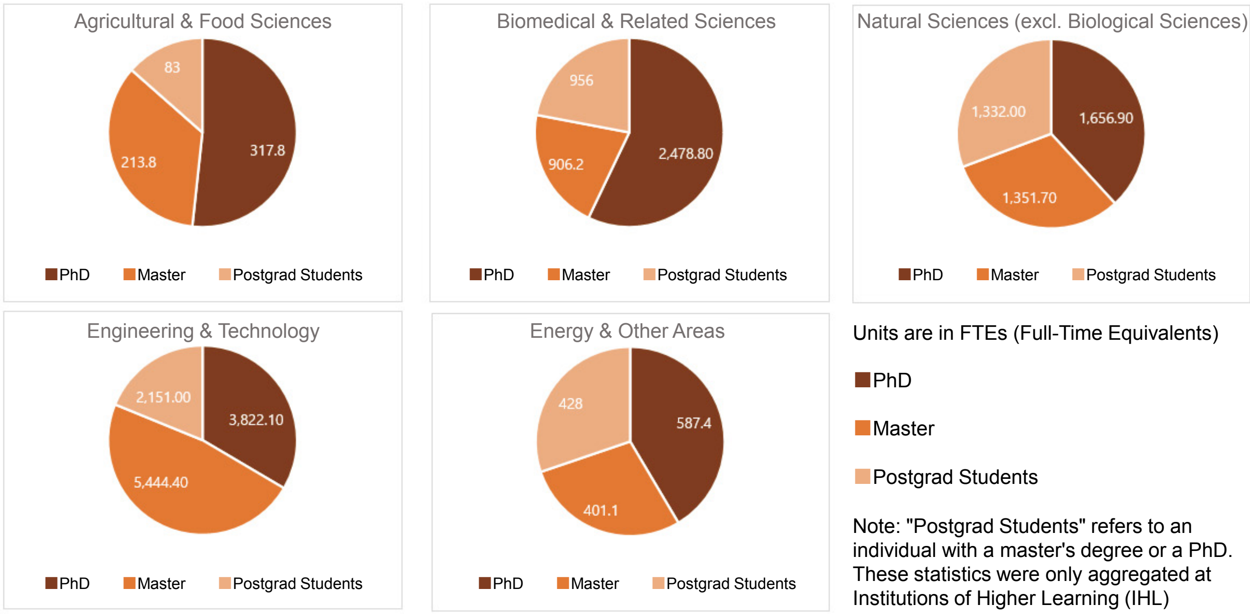

Figure 2-3: Distribution of degrees and number of researchers (by academic field)

Source: Same as Figure 2-2

Looking at the number of researchers by sector, in the private sector there is an overall increase regardless of the type of degree (Figure 2-4), and in the public sector there is a significant increase in the number of doctoral degree holders (Figure 2-5).

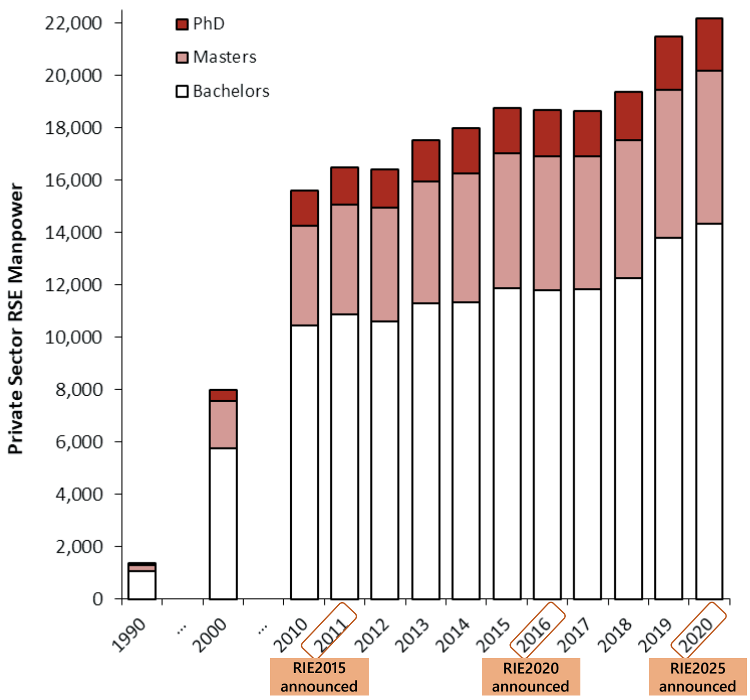

Figure 2-4: Number of researchers in the private sectors (1990 to 2020)

Source: Same as Figure 2-2

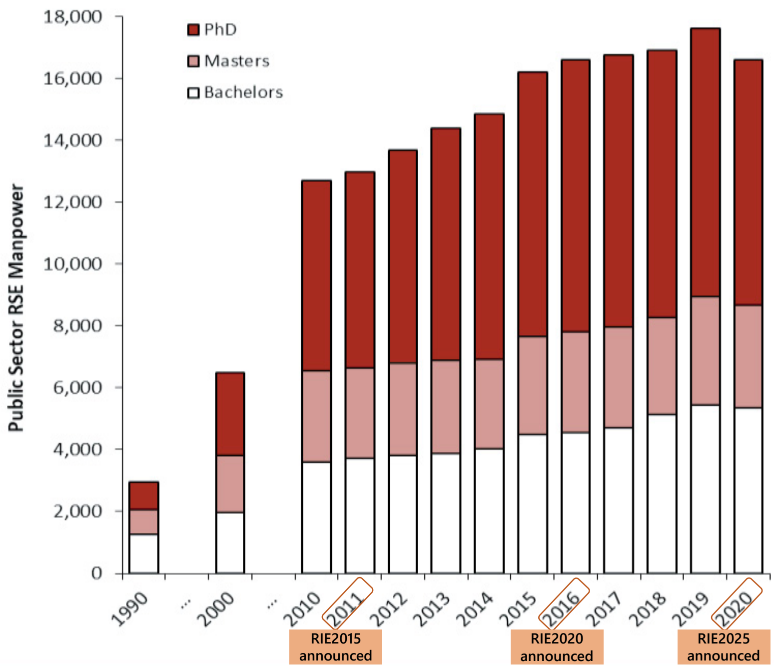

Figure 2-5: Number of researchers in the public sector (1990 to 2020)

Source: Same as Figure 2-2

In order to further see the depth of the support environment that supports research and development, this report looked at the number of research support staff by job type per researcher (Figure 2-6). The number of technicians is below 0.1 per researcher, except for in government agencies. On the other hand, the number of support staff in government agencies is more than 0.6 per researcher, which indicates that the system is relatively well-developed. As a point of comparison, in a similar survey[16] by NISTEP, in Japan the tendency is for government agencies to have a large distribution of support staff, including technicians, per researcher, so Singapore has a distribution trend that is very similar to the one found in Japan.

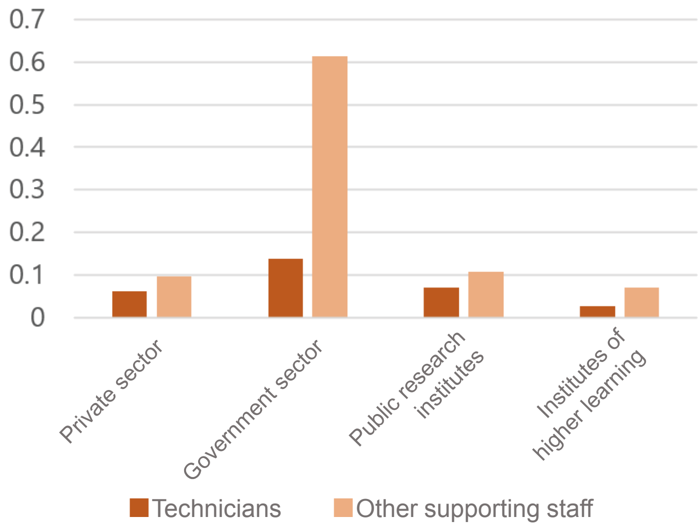

Figure 2-6: Number of research support staff by job type per researcher by sector

Source: Same as Figure 2-2.

[16] Japanese Science and Technology Indicators 2022, Figure 2-3-2; https://www.nistep.go.jp/sti_indicator/2021/RM311_29.html. However, as noted in the notes to this indicator, the definition and measurement methods for research support differ depending on the country, so care must be taken when making international comparisons.

Finally, this report looked at the number of researchers moving between Singapore, China, and the United States from 2006 to 2016 (Figure 2-7). Although Singapore does not have the same quantity of researchers as China and the United States, it has been sending and receiving science and technology human resources from both China and the United States, and it can be seen that Singapore has established exchanges with both countries that are beneficial to itself.[17]

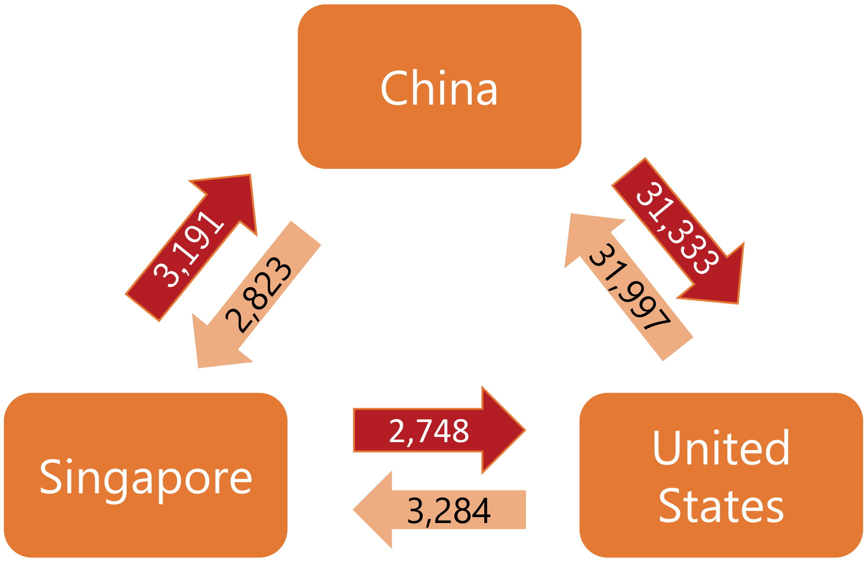

Figure 2-7: Primary international human resource flows in Singapore

Note: The values shown in the arrows represent the number of researchers traveling between the two countries (2006 to 2016). Mobile researchers here refer to the "Number of researchers" in "International bilateral flows of scientific authors, 2006-16" by the OECD.

Source: Created by the authors based on OECD "Science, Technology and Industry Scoreboard 2017"

[17] A previous survey by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) provided a bird's-eye view of the global flow of human resources. Figure 2-7 shows data on the primary Singapore-related flows of research personnel, and is an excerpt from scientific paper data for the 10 years from 2006.

2.2 R&D Expenditures and Ratio to GDP

Although total R&D expenditures (left axis) fluctuated from year to year, there was a clear overall upward trend until 2015. Since 2016, however, R&D expenditures declined, albeit very gradually. The ratio of R&D expenditures to GDP (right axis) peaked in 2008 and then declined, remaining at around 2% for the next 10 years (Figure 2-8).

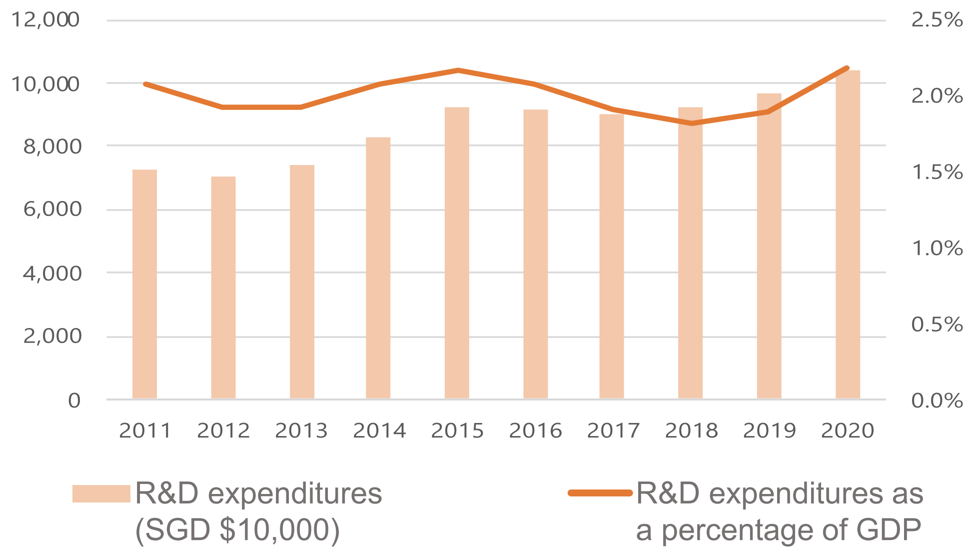

Figure 2-8: R&D expenditures and ratio to GDP (2011 to 2020)

Source: Same as Figure 2-2

Looking at the breakdown of R&D expenditures by research category (Figure 2-9), basic research accounts for the highest percentage in Energy & Other Areas, and the lowest in Engineering & Technology. On the other hand, experimental research accounts for the largest share, nearly 60%, in Engineering & Technology, while remaining at around 30% to 40% for all other categories.

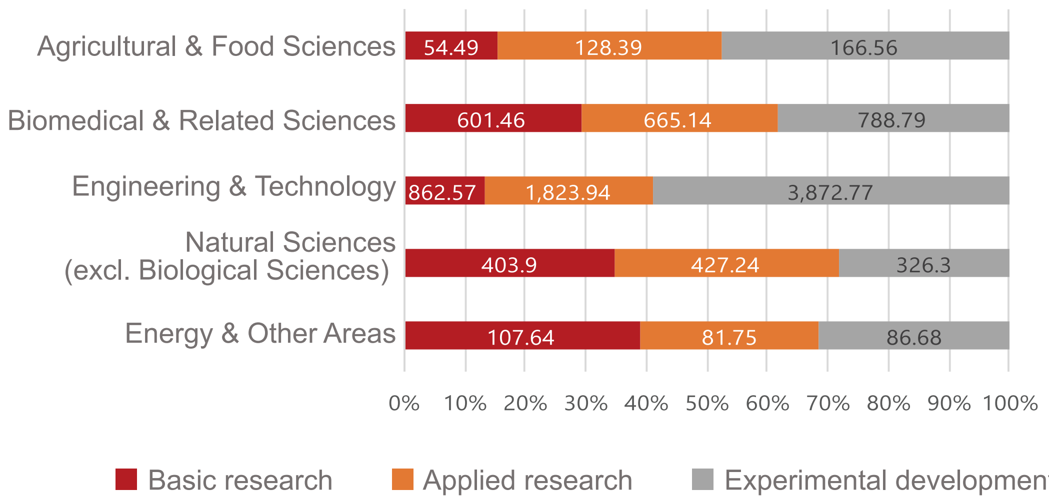

Figure 2-9: Breakdown of R&D expenditures by research category

Source: Same as Figure 2-2

2.3 Total Number of Papers and Singapore's Share (Overall)

The total number of papers published has consistently increased over the past 10 years, and, although Singapore's global share of the total number of papers peaked in 2017 and declined in 2019, it rose again to 0.79% of the total by 2021 (Figure 2-10).

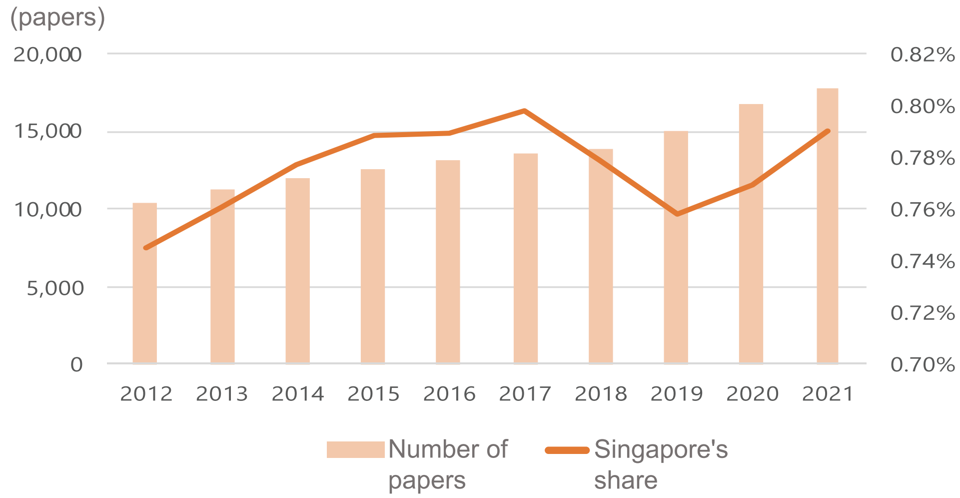

Figure 2-10: Total number of papers and Singapore' s share (2012 to 2021)

Source: Web of Science. Includes original publications and review articles from each year.

This report also looked at the "relative citation ratio (RCR)," which indicates the degree of attention a paper receives relative to the world average (Figure 2-11). Since 2011, Japan's relative citation rate has remained close to 1, which is the world average, while Singapore's RCR has almost consistently been rising since 2011, and for the past five years, Singapore has maintained a relative citation rate between 1.8 and 2.2, indicating that an extremely high level of attention compared to the world average.

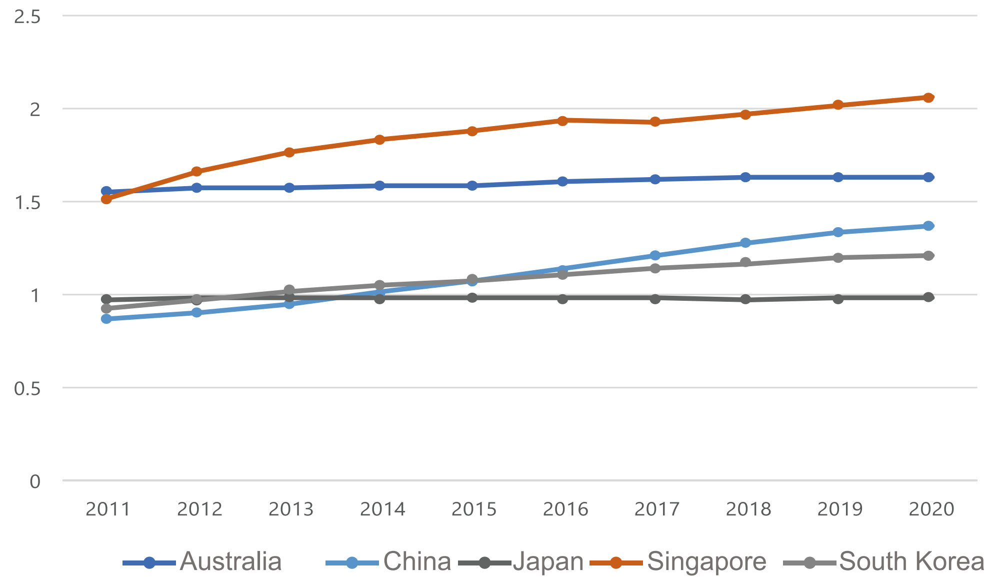

Figure 2-11: Relative Citation Ratio for five Asia-Pacific countries

Relative citation ratio is (number of citations per paper for each country) / (number of citations per paper worldwide). A value of 1.0 indicates the world' s average citation ratio. The number of citations and the total number of papers used in the calculations were cumulative values over a five-year period.

Source: APRC calculation from Clarivate Analytics and InCites Benchmarking

2.4 Number of Papers and Share (Top Papers)

Singapore's number of top papers consistently increased until 2019, a period of time when there was no impact from the COVID-19 pandemic, with Singapore's total number of top papers doubling from 10 years ago and Singapore's share of top papers increasing by approximately 1.3x over the past 10 years. Since 2018, Singapore's share of top papers has exceeded 3%, and in 2019 its number of top papers exceeded 500. Singapore's number of top papers slightly decreased in 2020, but then rose again in 2021 (Figure 2-12).

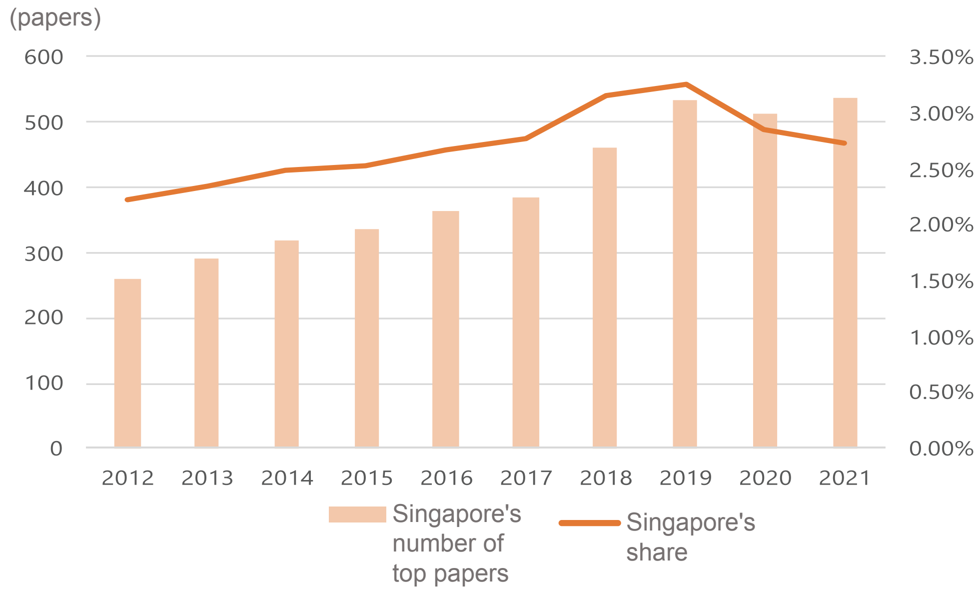

Figure 2-12: Singapore' s number of top papers and share of top papers (2012 to 2022)

"Top papers (ESI Top Papers)" is the sum of Web of Science' s top 1% papers and hot papers (papers published within the last two years that have received an extremely high amount of citations within the last two months).

Source: Web of Science

2.5 Investments in R&D and Scientific Research Capabilities as Seen by Number of Papers

In order to get an overview of whether Singapore's scientific research capabilities are commensurate with the R&D expenditures that it invests in comparison with the rest of the world, this survey compared Singapore's global GDP share, R&D expenditures to GDP ratio, global share of papers, and global share of the top 1% of papers with those of major global counties (United States, China, and Japan) (Table 2-1). As the table shows, although Singapore's ratio of R&D expenditures to GDP is not high when compared to other major countries, in terms of global share of the number of papers Singapore's share is approximately twice that of its global GDP share, whereas other major counties have a share that is roughly the same as or less than twice their global GDP share, and this can be interpreted as Singapore having scientific research capabilities that exceed their investment. Additionally, Singapore's share of the top 1% of papers is more than 7x its global GDP share. Because other major countries have a share of the top 1% of papers that is about the same or more than double their global GDP share, this can be interpreted as Singapore having R&D capacity that exceeds their investment in terms of research quality (this result also agrees with the "relative citation ratio" discussed in section 2.3).

Table 2-1: Comparison of GDP, R&D expenditures, number of papers, and number of top 1% papers for major countries

	GDP (global share)	R&D expenditures to GDP ratio	Total number of papers (global share)	Number of top 1% papers (global share)
Singapore	0.4	1.9	0.8	3.0
United States	24.6	3.4	22.9	40.0
China	17.5	2.4	16.8	37.0
Japan	5.9	0.0	5.0	47

Source: GDP is nominal GDP, 2020 values (from the Takashi Shiraishi lecture materials cited above). Singapore's number of papers (global share) is the 2020 value shown in Figure 2-10. For R&D expenditures, number of papers, and number of top 1% papers, the 2020 values from NISTEP "Japanese Science and Technology Indicators 2020" are used. The number of papers and number of top 1% papers are based on an integer counting method. All units are percentages.

2.6 Number of Patent Applications and Number of Patent Registrations

Over the past 10 years, Singapore's number of patent applications has continued to increase (slightly decreasing only in 2019), and its number of patent registrations has increased by approximately 1.8x (Figure 2-13).

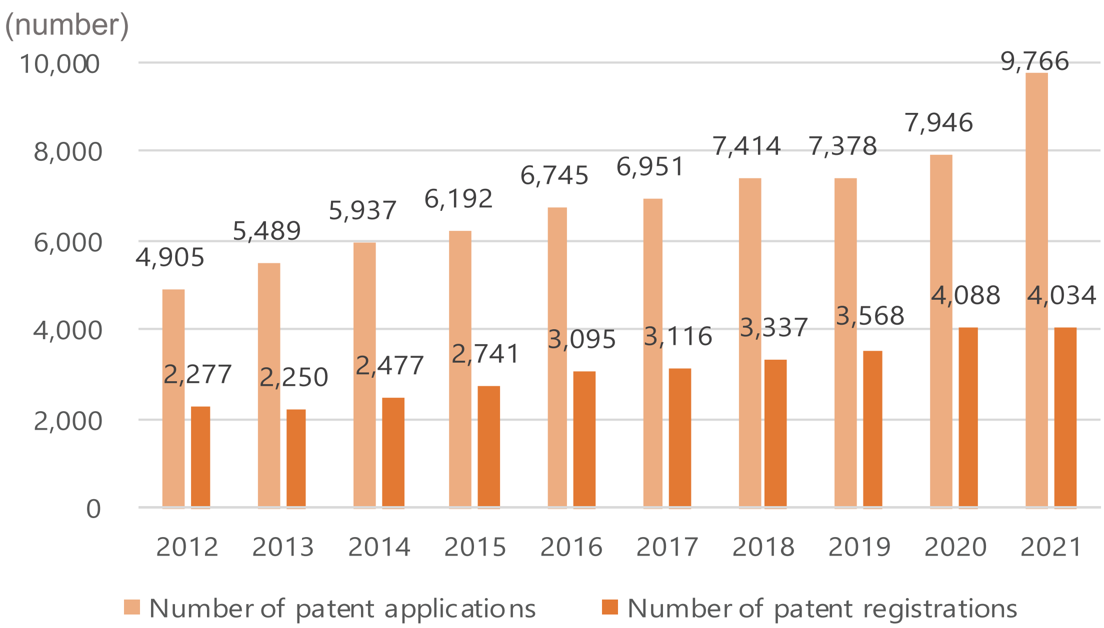

Figure 2-13: Number of patent applications and number of patent registrations (2012 to 2021)

Source: WIPO IPStats

2.7 University Rankings

The world rankings of universities that are leaders in research and development are listed for both QS and Times Higher Education (THE) (Tables 2-2 and 2-3). The National University of Singapore (NUS) topped both rankings.

Founded in 1905, NUS has a diverse research and education environment with approximately 38,000 students from more than 100 countries and regions around the world. It has 17 international joint degree programs, including joint degree programs with Yale University (which will stop accepting applications in 2022) and Duke University in the United States.

In particular, NUS has rapidly increased its research capabilities in the 21st century, surpassing the University of Tokyo, Peking University, and the University of Melbourne in the QS University Rankings and maintaining the highest rank in the Asia-Pacific region for five consecutive years since 2018. In addition to establishing eight affiliated research institutes and six Centres of Excellence (COE), NUS has established itself as a research hub in Asia and the Pacific by collaborating with major innovation hub cities around the world, including cities in the United States, China, India, and Sweden. NUS's proportion of international researchers has rapidly increased from approximately 10% of the total number of researchers on campus in the 1980s to 39% in 1997, and to a majority in 2007 to 2012.[18]

The development of NUS's scientific research capabilities is reflected in its outputs such as the number of papers and citations. In terms of patents, the Singapore has established a series of hub institutions with industry, such as the Technology Transfer and Innovation office (established in 1995), NUS Enterprise (established in 2000), as well as industry liaison offices, overseas colleges, and entrepreneurship centers. Singapore also allows ownership of intellectual property by researchers and departments, which has led to a steady increase in the number of national patent registrations[19]

Nanyang Technological University (NTU), which ranks second in both rankings, was founded in 1955 and is Singapore's second-largest comprehensive university with over 33,000 students, mainly in science and engineering departments. NTU's AI-related papers have received considerable attention in the field of information science, and have been the most cited papers for five consecutive years since 2012.[20]

When compared with the other universities in the Asia-Pacific region that rank in the top 30 in the world in terms of the eight category scores that compose the QS rankings (Table 2-4), it is clear that both NUS and NTU are highly rated for their internationality. While the remarkable internationalization of faculty and students can be expected to have advantages in terms of R&D, such as the acquisition of diverse ideas, the development of international collaboration, and the cultivation of international human resources, its disadvantages include the vulnerability of research and education infrastructure if international exchanges are cut off, as well as a reduction in opportunities for domestic talent to be trained and promoted.

[18] Ramakrishna, S. and V.V. Krishna (2017) "Research and Innovation in Asian Universities: Case study of the National University of Singapore," in V.V. Krishna (ed.) *Universities in the National Innovation Systems Experiences from the Asia-Pacific,* Oxfordshire, UK: Routledge, pp.254-257.

[19] Same as footnote 5.

[20] "Number of Artificial Intelligence Papers Make the US, China, and India the Top Three in the Innovation Roadmap 2030," Nihon Keizai Shimbun, November 1, 2017. https://www.nikkei.com/article/DGXMZO22943380R31C17A0TJU200/

Table 2-2: Top 1,000 universities in the QS World University Rankings 2023

Rank	University	Overall Score
11	National University of Singapore (NUS)	92.7
19	Nanyang Technological University (NTU)	88.4
511-520	Singapore Management University (SMU)	—

Source: https://www.topuniversities.com/university-rankings/world-university-rankings/2023

Table 2-3: Top 1,000 universities in the World University Rankings

Ranak	University	Overall Score
19	National University of Singapore (NUS)	87.1
36	Nanyang Technological University (NTU)	77.0

Source: https://www.timeshighereducation.com/world-university-rankings/2023/world-ranking

Table 2-4: Comparison of scores for top 30 Asia-Pacific universities in the QS World University Rankings 2023

University	NUS	Peking University	Tsinghua University	Nanyang Technological University	University of Hong Kong	University of Tokyo	Seoul National University
Ranking	11	12	14	19	21	23	29
Overall	92.7	91.3	90.1	88.4	87	85.3	82.2
Evaluation from academics	99.5	99.3	98.9	90.4	97.4	100	98.6
Evaluation from employees	94.1	96.5	97.7	76.1	62.9	98.7	97.8
Evaluation from undergraduate students	79.8	87.3	92.8	83.2	84.2	91.9	87
Citation rate per department	91.8	96.7	98.1	94.1	72.6	73.3	70.3
International department ratio	100	57.1	16.7	100	100	10.4	12.2
International student ratio	73.5	36.9	25.7	74.1	98.7	27.8	10.3
International research network	89.9	77.5	75.5	89.6	81.1	89.5	79.3
Employment outcomes	99.6	91.4	87.1	84.6	99	97.8	97.7

Source: Created by the authors from QS University Rankings data for each school

3 Basic Policies and Major Measures for Nurturing and Maintaining Science and Technology Human Resources in Singapore

This section takes a detailed look at Singapore's basic policies and major measures related to science and technology human resources.

First, this section will look at citations of, and policy priority for, nurturing and maintaining human resources in the country's medium- to long-term plans, and will then look at measures related to nurturing domestic researchers and measures related to inviting international researchers. Additionally, foreign students, particularly those who go on to graduate school or who are currently enrolled in graduate schools, can be regarded as a "reserve corps of researchers" who can become future science and technology human resources.

Other measures related to nurturing and maintaining human resources include secondary education for young individuals expected to become the next generation of researchers, as well as nurturing, securing, and expanding employment for highly skilled professionals in general, including those in fields other than science and technology (such as legal and financial, etc.). These issues are summarized in Section 3.6 and the results are discussed in Section 3.7.

3.1 Basic Policies for Nurturing and Maintaining Science and Technology Human Resources

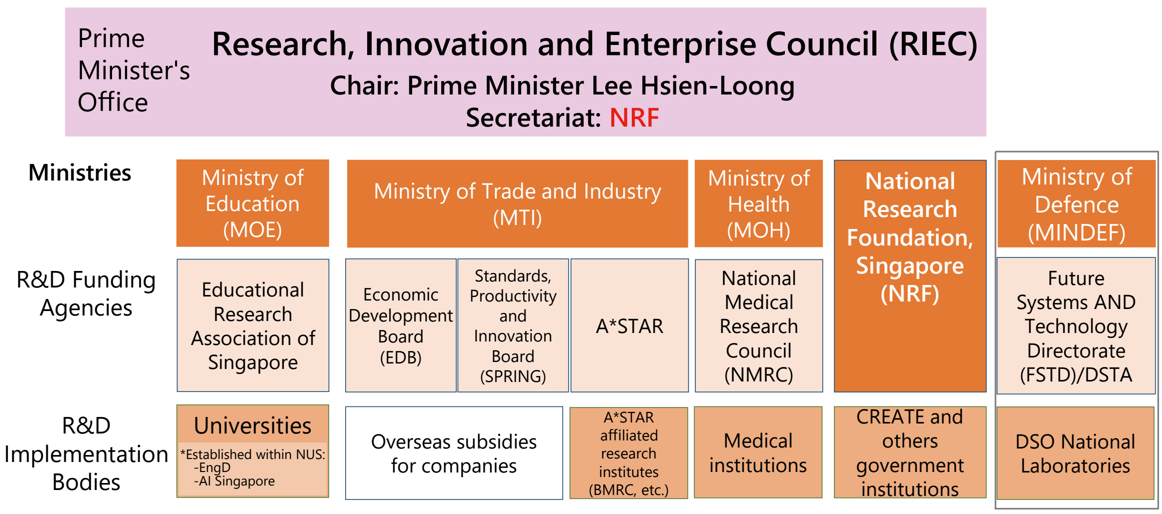

Figure 3-1: Singapore R&D governance and key institutions

Source: Created by the authors with reference to the relevant websites for each institution

Before looking at Singapore's basic policies, the main policy-related bodies are summarized in Figure 3-1. Singapore's R&D governance is centralized, with the Research, Innovation and Enterprise Council (RIEC), chaired by Prime Minister Lee Hsien-Loong, setting the direction for national policy. The National Research Foundation, Singapore (NRF), established in 2006 within the Office of the Prime Minister, is responsible for funding and overseeing the country's R&D activities. The NRF also determines the budget allocation for each ministry and advises the RIEC on national issues.

The NRF allocates its budget through a combination of top-down and bottom-up, institutions of higher learning (IHL) and public research institutions. Top-down programs include biomedical sciences, environmental and water technology, and interactive digital media. Bottom-up programs include competitive research programs, grants for interdisciplinary cutting-edge research teams, and Research Centres of Excellence (RCOE, a long-term investment program to establish world-class research centers at domestic universities). Funding is provided directly by the NRF, as well as by individual ministries and agencies in each research area. The Ministry of Health (MOH) is responsible for clinical medicine, the Ministry of Education (MOE) for basic research, and the Agency for Science, Technology and Research (A*STAR) for biomedical and engineering research.

As part of its economic policy, Singapore's science and technology policies are also placed under the Ministry of Trade and Industry (MTI), the Infocomm Media Development Authority (IMDA), and the Ministry of Education. Employment and development of highly skilled human resources, including scientific and technical personnel, is under the jurisdiction of the Ministry of Manpower (MOM).

Amongst the policy-implementing entities under the MTI umbrella, A*STAR in particular was established in 2002 by reorganizing national research institutions, plays an important role in determining research priorities as a major source of public R&D funds, and provides competitive funding to researchers at public research institutions in fields prioritized by the country and A*STAR (biomedical, physical science, and engineering (the Biomedical Research Council [BMRC], described below, has jurisdiction over biomedical science). The Singapore Economic Development Board supports large and international companies that are entering into Singapore, and Enterprise Singapore provides support for small- and medium-size enterprises, including start-ups.

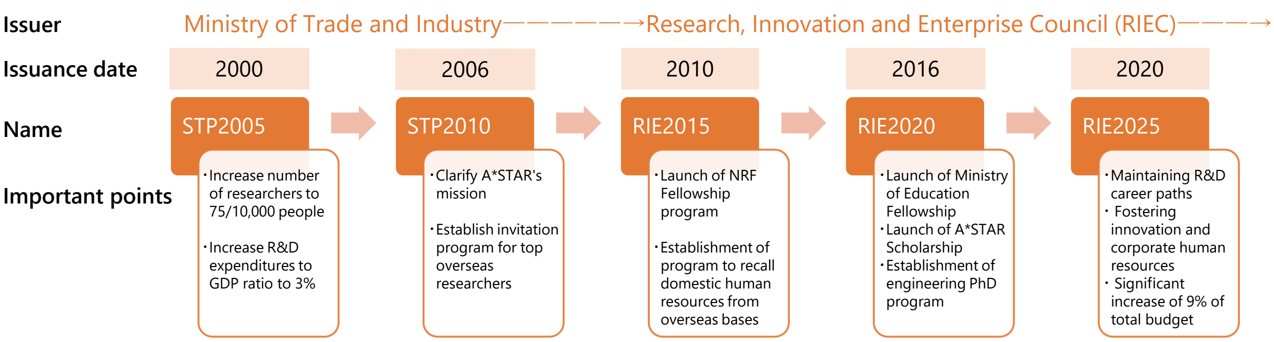

Figure 3-2: Singapore' s previous five-year plans and their key points

Source: Created by the authors with reference to each issuer' s websites.

Singapore's five-year plan, which sets medium- to long-term guidelines for the promotion of science and technology, was first formulated in the "Science and Technology Plan" covering the period 1991-95, and since then has been formulated every five years (Figure 3-2). The following is a summary of the main points of references to nurturing and maintaining human resources in each of the documents released since 2001, when the content of the policy documents became more concrete.

The Science and Technology Plan 2005 (STP2005), announced in 2001, touched on two points: (1) Increase the number of science and technology human resources per 10,000 people to 75 individuals per 10,000 people (figure in 1999: 70 individuals per 10,000 people), and (2) Increase R&D expenditures to GDP ratio to 2-3%, on par with that of developed countries (figure in 1999: 1.84%). At the time, only quantitative targets for major inputs in science and technology policy were set.

Subsequently, STP2010, published in 2006, included a chapter entitled "Developing and Managing R&D Human Capital," and the mission of A*STAR was clarified to "to develop and sustain a strong pipeline flow of PhD talent to meet industry needs."[21] Led by A*STAR, STP2010 established a program (described later in this report in section 3.4) to invite outstanding international researchers in various fields to Singapore, and also recommended research careers for outstanding domestic human resources. By thus achieving a balance between domestic and international science and technology human resources, Singapore created a sufficient base of established human resources to support national R&D, and envisioned sustainable, medium- to long-term scientific and technological development.

From 2011, the Science and Technology Plan was renamed as "Research, Innovation and Enterprise (RIE)," and its first document, RIE2015, included the following key measures: (1) the establishment of a scholarship system by NRF, (2) an NRF program for recalling personnel (the "Returning Singaporean Scientists Scheme," described below in section 3.3), and (3) the establishment of a human resources program at the Ministry of Health (MOH).[22] Compared to the plans of the previous decade, the emphasis shifted from "inviting top overseas researchers" and "promoting the study abroad of Singaporean researchers" to "nurturing Singaporean researchers" and "recalling outstanding Singaporean researchers who are active overseas."

RIE2020's main initiatives included research scholarships from the Ministry of Education (MOE), various scholarship programs from A*STAR, and the Doctor of Engineering (EngD) program.[23] With the cooperation of not only Singapore's ministries and agencies but also of domestic and international academia, the idea was to maintain and develop existing measures for nurturing human resources, expand the target fields, and produce human resources who could immediately respond to diverse needs in industry that were beginning to grow at the time.

The most recent five-year plan, RIE2025, under its "Nurturing Talent" section, also calls for (1) maintaining career paths for R&D personnel, (2) nurturing innovation and corporate human resources, and (3) supporting research centers for technology fields with high demand, such as digital technologies. [24]In particular, in terms of budget, $2.2 billion SGD (approximately 220 billion JPY), a significant amount that is equivalent to 9% of the total RIE2025-related budget (approximately $25 billion SGD [2.5 trillion JPY]), was invested in nurturing human resources. This investment is in response to recognition from overseas that Singapore is "Asia's most innovative economy," and, in

21 Refer to RIE2010, pp.36-37. https://www.mti.gov.sg/-/media/MTI/Resources/Publications/Science-and-Technology-Plan-2010/s-and-t-plan-2010.pdf

22 Refer to RIE2015, p.12. https://www.mti.gov.sg/Resources/publications/Research-Innovation-and-Enterprise-RIE-2015

23 Refer to the original report on the NRF website.https://www.nrf.gov.sg/docs/default-source/Publications/rie2020-publication-(final).pdf#page=18

24 SPAP Basic Materials Collection. Some translations have been changed for the context of this paper. https://spap.jst.go.jp/resource/pdf/aprc-fy2022-pd-sgp01.pdf#page=49

order to further strengthen this recognition, greater emphasis is being placed on nurturing human resources than in the previous medium- to long-term plans.[25]

While these medium- and long-term plans are being conceived and implemented by government agencies in science and technology, higher education in Singapore is also announcing its own measures. In 2015, the Ministry of Education established START (Singapore Teaching and Academic Research Talent Scheme). START is a scheme targeting four autonomous universities[26] to nurture domestic human resources who can be active players in the research, development, and academic fields. The purpose of the program is to provide undergraduate and graduate scholarships to help autonomous universities strengthen their pool of talented human resources in education and research fields (23 awards were endowed in 2022). The award recipients will be able to begin teaching and research careers in Singapore after studying at domestic or overseas educational institutions.

The Ministry of Education announced the expansion of START at the 8th START Award Ceremony held on September 14, 2022.[27] It was announced that the Singapore Institute of Technology (SIT) and the Singapore University of Social Sciences (SUSS) would be added to the four existing autonomous universities under the scheme.

3.2 Primary Measures Related to Nurturing and Maintaining Researchers Domestically

In Singapore, the primary measures by the NRF and A*STAR related to domestically nurturing and maintaining science and technology human resources are scholarships to support study by undergraduate and graduate students, and grants (fellowships) to support the research activities of young researchers. The Ministry of Education also offers scholarship programs that are limited to some universities in the country. These systems are covered in order below.

3.2.1 NRF Grants and Research Support Programs

As mentioned earlier, the NRF's role is as a command and control post for national policies. In particular, in order to achieve its mission of "Building up R&D capabilities and capacities through nurturing our people and attracting foreign researchers and scientists," it provides financial support by offering research grants of up to five years to young researchers, thereby giving them opportunities for independent research activities.

The NRF Fellowship was launched in 2008, shortly after the NRF was established, with a budget of $3 million SGD (approximately 300 million JPY) over five years. In the FY2024 call for submissions, the scale of the project was expanded to a budget of $2.5 million SGD (approximately 250 million JPY) per year to support the domestic

[25] As of 2014, the total amount of funds allocated by NRF to research institutions was $5 billion SGD. The budget of $25 billion SGD that was earmarked for RIE2025 is five times this amount. "RIE2025: Behind Singapore's S$25 Billion R&D Budget" Asian Scientist, December 11, 2020 https://www.asianscientist.com/2020/12/topnews/rie2025-singapore-research-budget/

[26] "Autonomous universities" refers to six universities: NUS, NTU, SMU, SUTD (Singapore University of Technology and Design), SIT, and SUSS, which are universities/research institutions with a strong R&D orientation or which have applied courses for industry. START initially targeted the first four schools. Refer to the Ministry of Education website below. https://www.moe.gov.sg/post-secondary/overview/autonomous-universities/

[27] Singapore Ministry of Education, press release dated September 14, 2022. https://www.moe.gov.sg/news/press-releases/20220914-expansion-of-singapore-teaching-and-academic-research-talent-scheme-a-boost-for-singapores-pipeline-of-research-talent

research activities of young researchers who have obtained their PhD (includes international researchers). The open call for submissions is held every winter, and, after a two-stage selection process, approximately 10 individuals will be selected for the fall of the following year. A total of 130 individuals have been selected as of the end of 2022, and 12 new individuals have been selected for FY2023.[28] The host universities are primarily autonomous universities, including A*STAR, NUS, NTU, Duke-NUS Medical School, SMU, and Temasek Life Sciences Laboratory (TLL). In FY2018, sector-specific grant programs, such as for AI, were also offered.[29] Similar to the NRF Fellowship, this program provides support of up to $3 million SGD (300 million JPY) over five years for domestic research activities to young researchers who have earned a PhD in AI or related information science fields.

The NRF Investigatorship, launched in 2015, is a five-year, $2.5 million SGD research grant program for mid-career researchers working in innovative, high-risk topics.[30] There is an open call for applications once a year, and, by the end of November 2022, a cumulative total of 54 researchers had been selected, with an additional 15 researchers selected for FY2023.[31]

The international fellowship program is being developed by CREATE (Campus for Research Excellence and Technological Enterprise), which was approved in 2006. It is an international collaborative research center established in Singapore by world-class universities and research institutions, including Massachusetts Institute of Technology (MIT), Swiss Federal Institute of Technology Zurich (ETH), University of Cambridge, Technical University of Munich, and Hebrew University, and provides mid-career to senior-professor-level researchers with the opportunity to flexibly collaborate on cutting-edge research problems. The fellowship, which collaborates with environmental measurement, modelling, and micromechanical engineering, provides a 12-month salary, including travel and lodging, for a period not to exceed four years. The areas covered range from urban engineering and energy technology to food, health, decarbonization, AI, and cybersecurity, and various international research programs are launched every year.

3.2.2 A*STAR Scholarship Programs

As previously mentioned, A*STAR was established under the Ministry of Trade and Industry for the purpose of promoting joint research amongst research institutions. As of March 2023, it has 14 engineering research institutes and 12 medical/life science research institutes,[32] and is leading strongly exit-oriented research and development by promoting industry-academia collaborations.

A*STAR's scholarship system for science and technology personnel was established for graduate students (master's and doctoral students) and postdoctoral researchers. Table 3-1 shows an overview of the latter two.

[28] This list of Fellows who were selected as of the end of 2022 is published below: https://file.go.gov.sg/nrff-dec2022.pdf

[29] The first call for applications (with a grant period of up to 2023) was announced in the relevant fiscal year (https://www.nus.edu.sg/research/docs/default-source/nrf-ai/infonote_for_nrf-fellowship_for-ai.pdf). However, from publicly available information it was not possible to confirm whether or not this project continued into the next fiscal year and beyond.

[30] Refer to the NRF website. https://www.nrf.gov.sg/funding-grants/nrf-investigatorship

[31] The list of Fellows who were selected as the end of November 2022 is published below: https://file.go.gov.sg/nrfi-nov2022.pdf

[32] Refer to the A*STAR website (as of March 2023)https://www.a-star.edu.sg/docs/librariesprovider1/default-document-library/about-a-star/astar-organizational-chart, https://www.a-star.edu.sg/about-astar/research-entities

Table 3-1: A*STAR Scholarship Programs

Program Name	A*STAR International Fellowship (AIF)	National Science Scholarship (PhD)	A*STAR Graduate Scholarship (Overseas)	A*STAR Computing & Information Science (ACIS) Scholarship	Singapore International Graduate Award (SINGA)	A*STAR Research Attachment Programme (ARAP)
Application Requirements	Singaporean citizens. International individuals must have acquired Singaporean citizenship before receiving the scholarship.	Singaporean citizens or permanent residents who wish to acquire citizenship		Singaporean citizens. International individuals must be enrolled in a specialized course in computing or information science at an autonomous university in Singapore or must have obtained (or are expected to obtain) an equivalent degree.	International individuals	Doctoral students (international individuals) enrolled at a partner university
Place of Study	Top global universities and research institutions (general natural science majors)	Biomedical, natural science, and engineering majors at top global universities	A*STAR research institution for the first 2 years, then at one of 9 designated universities for the next 2 years	Departments of Computer Science and Information Science at NTU, NUS, SMU, and SUTD	A*STAR research institutes or biomedical, natural science, or engineering majors at NTU, NUS, and SUTD	A*STAR research institutions
Period	Up to 2 years	Up to 5 years	Up to 4 years	Up to 4 years (incl. up to 12 months of international study)	Up to 4 years	1 to 2 years
Scholarship Details	Monthly allowance, year-end return home allowance, tuition fees, conference participation fees, year-end personal insurance premiums	Full tuition fees, living expenses, book/computer purchase costs, and conference participation fees, etc.		Monthly allowance of $4,500 to $5,800 SGD (depending on nationality), books, ICT, academic conference participation, and paper writing expenses	Monthly allowance of $2,000 SGD ($2,500 SGD after passing exam), tuition fees, and conference participation fees	Monthly allowance of $2,700 SGD, travel expenses of $1,500 SGD, and conference participation fees
Obligations After Completing Program	Return to Singapore and work at an A*STAR research institution for 3 years	Work at an A*STAR research institution for 4 years after obtaining PhD	Work at an A*STAR research institution for 3 years after completing the program	Individuals who are not Singaporean citizens must work in a related industry at a Singaporean company for 3 years	None	None
Other Incidental Conditions	Within 4 years of obtaining a PhD, outstanding publication performance, and application for recruitment at a related top foreign research institution	In come cases, individuals may be required to participate in ARAP at an A*STAR research institution for one year before starting the doctoral program		None	None	None
Eligibility	Postdoctoral researchers	Doctoral students				

All amounts in the table are in Singapore dollars (SGD). Note that some support systems for studying abroad are also included.
Source: Created by the author with reference to Iwasaki (2015) and the A*STAR website.

Many of A*STAR's scholarship programs, like the NRF Fellowship, are open to international individuals and are unique in that they allow students to study not only at domestic universities but also at top global universities. However, most of the programs require the recipients to work at an A*STAR research institution for three to five years after receiving their degree. In recent years, in response to the realization of the Smart Nation concept in RIE2025, a new scholarship system has been established for industries that are more exit-oriented, such as information science and engineering.

3.2.3 Grant and Research Support Programs by the MOH and Related Agencies

The MOH's grant programs are overseen by MOH Holdings, a state-owned company under its umbrella. The National Medical Research Council (NMRC) also supports the development of young researchers through funding. Since 2006, the MOH has been focusing on leading, promoting, coordinating, and funding the medical field in collaboration with the NMRC, with the aim of strengthening bridging and clinical research, which has high national potential. Programs from both organizations for scientific and technical personnel have been extracted and listed in Table 3-2.[33] The NMRC was established in 1994, and the grant programs were established in the early 1990s.

[33] Refer to the MOH Holdings grants website (https://www.mohh.com.sg/programmes-partnerships/scholarships) and the NMRC website https://www.nmrc.gov.sg/grants/talent-development). The NMRC's latest deadline for the open call for submissions has already passed and is currently unavailable for viewing, so the information in this table is based on information that was obtained before February 6th.

It can be inferred that these programs form the backbone of the government's efforts to strengthen the biomedical sciences, and are linked to invitations of top international researchers and the establishment of R&D clusters.

In particular, the Singapore Translational Research [STaR] Investigator Award was established to bring experienced and world-class scientists to Singapore. Eligible applicants are researchers with a clinical degree and advanced professional background, or those with a doctoral degree who are active in clinical research areas such as epidemiology and biostatistics. The award has nearly three times as much research funding as other positions, and the annual salary is extremely high.

Table 3-2: Grant and Research Support Programs by the MOH and Related Agencies

Support System Name	STaR Investigator Award	Clinician Scientist Award	Clinician Innovator Award	HPHSR Clinician Scientist Award	Healthcare Graduate Studies Award
Overview	Support system for outstanding researchers in bridging research (TCR), health promotion, preventative medicine, epidemiology, and medical engineering.	Support system for outstanding clinical medical researchers	Commercialization support for researchers who have shown innovative ideas in clinical medicine	Support system for outstanding clinical medical researchers in the field of epidemiology	Support for the development of advanced human resources for outstanding graduates who wish to obtain a master's degree in health science. Professors in the fields of audiology, speech therapy, clinical psychology, epidemiology/public health, medical informatics, and public healthcare.
Application Requirements	High achievements in medical research, medical degree (or the equivalent of a doctoral degree for nursing), and a track record of clinical research or medical research.	Must be a licensed clinician and have received professional education at a medical or dental school (includes specialists, family physicians, and public health professionals. Must be currently conducting clinical or medical research. Health science professionals with a PhD or equivalent may also apply.			Students enrolled in their final year of undergraduate study or recent university graduates. Honours Bachelor's Degree (Second Class [Upper] Honours or equivalent)
Fellowship Support Details	Research expenses: $6 million SGD, PI annual salary: $600,000 SGD, all direct expenses, and 30% indirect expenses.	Depending on the grade given by NMRC, the annual salary ranges from $120,000 to $300,000 SGD, research expenses range from $700,000 to $1.8 million SGD, and 30% of indirect expenses.			Tuition fees, monthly allowance, some training programs, and support while studying abroad (advance allowance, and round-trip airfare)
Obligations and Incidental Conditions	Must be based in Singapore and enrolled at a domestic medical research institution for at least 9 months while receiving the grant.	Only one application may be submitted for each round of fellowship applications; if an applicant's first application is not selected, they may reapply up to two times.			None in particular
Eligibility	Researchers and individuals who have obtained a PhD. Nationality doesn't matter.				Individuals with a bachelor's degree who are Singaporean citizens or permanent residents who intend to become a Singaporean citizen

All amounts in the table area in Singapore dollars. Note that the table also includes programs that are less focused on nurturing human resources.
Source: Created by the authors with reference to the MOHH and NMRC websites.

3.2.4 MOE/Autonomous University Scholarship Program

The MOE-AU Scholarship[34] program was established as part of the aforementioned START under the RIE2020 five-year plan that began in 2015.This is a system that supports living expenses and tuition fees for graduate students in master's and doctoral courses who enroll at autonomous universities, rather than at any university in Singapore. The system can also be used to support postdoctoral researchers and university staff.

The following points are listed as requirements that applicants must meet:

- Singaporean citizens or permanent residents who have acquired Singaporean citizenship before the start of receiving benefits.
- Individuals who have demonstrated a strong desire to pursue an academic career at an autonomous university in Singapore.
- Applicants can apply for either [Full-term] or [Mid-term]. [Full-term] Applicants must have passed the university entrance examination or be enrolled in a pre-college program, or [Mid-term] Applicants must have completed at least one semester of university studies and not be in their final year of study.

[34] Refer to the MOE website. https://www.moe.gov.sg/financial-matters/awards-scholarships/moe-au-scholarship

3.2.5 Engineering Doctorate (EngD) program

The Engineering Doctorate program is a degree program that was established by the Academy of Engineering Singapore in July 2015.[35] It was established with the aim of meeting the needs of both industry and government, and through it the Singapore Economic Development Board (EDB) supports doctoral candidates that are dispatched by companies through the Industrial Postgraduate Programme (IPP).

The first schools accepting graduate students through the program were NUS and Singapore University of Technology and Design (SUTD). To date, the program has accepted 29 doctoral candidates from multinational companies operating in Singapore and research institutions such, as AI Singapore (see below) and A*STAR, with the first three students completing their doctoral studies in 2021, two of whom are women.

Although this program has only been in existence for a short time, particular emphasis has been placed on producing professional human resources (including technology management) that meet cutting-edge needs in industry. The program covers eight areas, including renewable energy, connected cities, sustainable cities, and cybersecurity, indicating that it addresses the priority areas set forth in the Smart Nation initiative announced in 2014.

3.2.6 AISG PhD Fellowship Programme

The AISG PhD Fellowship Programme is a new field-specific degree program led by AI Singapore (AISG), which was established in May 2017.[36] AI Singapore is a scheme that brings together AI-related research institutions; is comprised of research, governance, technology, and innovation segments; and aims to produce world-class AI science and technology talent from Singapore.

An outline of the program is as follows:

- The applicant's nationality is irrelevant.
- Via the program, four autonomous universities (NTU, NUS, STU, and SUTD) are accepting individuals who wish to obtain a doctoral degree in the AI field.
- Has five research clusters, focused on trust, privacy, resource efficiency, collaborative AI, and continuous learning.
- Fellows are expected to participate in other pillars of AI Singapore (pillars: research on AI technologies/concepts, research on AI governance, and AI innovation creation, etc.) and contribute to the entire AI ecosystem.
- Fellows receive a competitive grant of $6,000 SGD (600,000 JPY) per month, greater visibility in global academia, up to four years of study support, and opportunities to publish in top journals.

35 Refer to the Academy of Engineering Singapore website. https://www.saeng.sg/singapores-engineering-doctorate-engd-pioneers/

36 Refer to the AI Singapore website. https://aisingapore.org/research/phd-fellowship-programme/

3.3 Primary Measures Related to Nurturing and Maintaining Overseas Researchers

This section looks at measures related to nurturing and securing overseas researchers, as well as scholarship systems to support domestic researchers who are studying abroad.

As listed in Table 3-1, A*STAR offers a wide range of programs in Singapore that are suitable for this purpose. The National Science Scholarship for doctoral students and the International Fellowship for post-doctoral researchers can be seen as systems that are the equivalent of supporting international study for young Singaporean researchers. Additionally, A*STAR has established a doctoral program in partnership with the University of Warwick in the United Kingdom to foster industry-oriented human resources with a focus on applied sciences, although the program is limited to one institution. These include the A*STAR Research Attachment Programme,[37] a research internship program in partnership with the Warwick Medical School, and the A*STAR-University of Warwick EngD Partnership,[38] an engineering doctorate partnership with the Warwick Manufacturing Group. Both programs are open to Singaporean citizens and foreign nationals wishing to become Singaporean citizens, and require that applicants meet the admission criteria for each department at the University of Warwick and have (or expect to obtain) a relevant degree. The program supports four years of study, two years each at the University of Warwick and A*STAR, and requires three years with an A*STAR research institute after returning to Singapore.

Singapore also has the “Returning Singaporean Scientists Scheme” (RSSS), which is a measure to bring back outstanding homegrown researchers who are active overseas. The program was announced by the NRF in October 2013, and is a policy to encourage outstanding research leaders who are currently based overseas to return to Singapore as leaders at autonomous universities and public institutions. According to local news reports at the time, it was positioned as a “major science and technology promotion policy of the 2010s, along with innovation clusters and national cybersecurity research and development, which were announced at the same time.”[39]

The NRF has closely worked with senior leaders in Singapore to discover the next generation of leaders and has conducted a variety of efforts to encourage them to return to Singapore. The NRF also plans to provide start-up funds of $7.5 million SGD (approximately 750 million JPY) as an incentive. The goal for returning researchers via these measures was “10 individuals by 2019,” but the actual number is six individuals by 2022, as shown in Table 3-3.[40]

[37] Refer to the University of Warwick website. https://warwick.ac.uk/fac/sci/med/study/arap

[38] Refer to the A*STAR website. https://www.a-star.edu.sg/Scholarships/for-graduate-studies/a-star-university-of-warwick-awp-engd-partnership

[39] “Singapore Implements Scheme to Bring Home Top Scientists,” Asian Scientist article dated October 29, 2013.

[40] As published by NRF. https://www.nrf.gov.sg/programmes/returning-singaporean-scientists-scheme

Table 3-3: List of Singaporean Researchers Who Have Returned to Singapore

Name	Current Affiliation	Affiliation Before Returning to Singapore	Field of Expertise
Ho Teck Hua	Senior Deputy President and Provost of NUS	William Halford Jr Family Professor of Marketing at the University of California	Behavioral economics and data analysis
Aaron Thean	Electrical and Computer Engineering Professor at NUS, and Director of Industry-Academica Collaboration	Vice President of Logic Technologies, IMEC (Nanoelectronics Institute)	Microelectronics
Chua Nam Hai	Professor at Temasek Life Science Institute	Andrew W. Mellon Professor Emeritus at Rockefeller University	Plant science
Peh Li-Shiuan	Provost' s Chair Professor in the Department of Computer Science at NUS	Computer Science Professor at MIT	Electrical engineering
Khong Pek-Lan	Professor in the Clinical Imaging Research Centre at NUS	Clinical Professor and Head of the Department of Diagnostic Radiology at University of Hong Kong	Diagnostic radiology
Luke Ong Chih-Hao	Distinguished University Professor at NTU	Professor, Merton College, Oxford University	Computer science

Source: Created by the authors with reference to the Singapore National Research Fund website.

Column: Profiles of Researchers Who Returned to Singapore

What are the backgrounds of the researchers who came back under the Returning Singaporean Scientists Scheme? This column introduces a glimpse of their backgrounds from back issues of the Straits Times, which featured interviews by NUS, the host school, with the individual researchers.[41]

Aaron Thean earned his doctorate from the University of Illinois at Urbana-Champaign in the United States, and then worked as an in-house researcher at IBM, where he was involved in the production of transistors using new materials such as halfnium oxide. He holds over 50 patents and has published more than 200 original papers (as of the time of article). He said that he had two reasons for returning to Singapore. The first was his parents, who were in their 70s in Singapore at the time, and the second was the Smart Nation initiative launched by the Prime Minister's Office in 2014 (mentioned above). "Singapore is unique because we have a national effort to build the country into a smart nation. This means that we have fundamental support from the Government which is an edge over the United States or Europe, for instance, where such efforts occur only in the private sector," said Dr. Thean. He thought that he could use his expertise to help develop Singapore while also caring for his parents, so in May 2016 he decided to return to Singapore in response to the program and took up a post at NUS. Even though Singapore is his home country, he had already lived in the United States with his family for a long time, so he had to make numerous adjustments to his life.

Andrew Lim specializes in web platform development and operations research (OR), which calculates optimal plans. He is an engineering researcher who is deeply interested not only in scientific research but also in industrial applications and the commercialization of science, and has been involved in founding and managing five startups.

[41] Compiled from a series of Straits Times articles published on January 8, 2016. "Singapore Scientist behind Transistor Revolution," "Back home to inspire the next generation," "Biotech expert returning here to research super crops," January 8, 2016. The Straits Times.

After 12 years of research at the Hong Kong University of Science and Technology, City University of Hong Kong, and Nanjing University, he returned to Singapore in 2013 and took up his post at NUS. Based on his own experience in starting a business, he said, "I want to inspire the young people in my home country who will lead the next generation, and cultivate their entrepreneurial spirit.'"

Chua Nam Hai is a world-renowned biotechnology expert; His ambition is to develop agricultural products with high yields and high resistance to environmental stress, and to help solve the problem of world hunger. He moved to the United States in 1971 to attend Rockefeller University, and, while continuing his research activities, founded the Institute of Molecular Agrobiology in Singapore in 1995, and in 2002 established Temasek Life Sciences Laboratory. He travels back and forth between New York and Singapore and says he has had no problems adjusting to the lifestyles. One of the reasons he decided to return to Singapore in 2015 was the remarkable improvement in the research environment over the past 20 years. "When I moved to the United States, the research environment in Singapore was poor, but, if conditions had been the same as they are right now, then I might have stayed in Singapore." Professor Chua is continuing to work towards making Singapore the Asia-Pacific center for agricultural technology research.

3.4 Primary Measures Related to Inviting International Researchers

In promoting science and technology, inviting top researchers in each field from abroad has an immediate effect on rapidly catching up with developed countries. Since the early 21st century, Singapore has been at the forefront of the world in inviting such top researchers.

A*STAR in particular has played a central role,[42] with the most symbolic project being Biopolis, which was established by the first Chairman of A*STAR. Biopolis, which clustered top international life science researchers in the One-North region, dramatically raised Singapore's level of research in one stroke. Together with neighboring NUS, National University Hospital, and the National Science Park, Biopolis become a public-private R&D cluster in the biomedical field.[43] Following the Biopolis model, Mediapolis for the information field and Fusionopolis for engineering and interdisciplinary science then successively established.

Additionally, the following programs to invite international researchers are also being implemented.

The Distinguished Visitors Programme (DVP) is led by A*STAR and invites world-leading researchers in a variety of fields, thereby providing young Singaporean researchers to keep up with cutting-edge trends in science and technology, and DVP is help for the purpose of promoting interaction with the world's science and technology community.[44], [45]

42 Kori, Iwasaki (2015) "Singapore's Strategy for Attracting Highly Skilled International Human Resources: How Does the Country Attract Highly Skilled Human Resources?" *Pacific Rim Business Information* 15(57), especially pp.59-61. https://www.jri.co.jp/MediaLibrary/file/report/rim/pdf/8159.pdf#page=14

43 For an overview of Biopolis and Fusionopolis and the formation of the R&D clusters surrounding them, Ramakrishna and Krishna (2017) pp.252-253 was also referred to.

44 RIE2010, p.37. In 2002, Professor Sir George Radda was invited to become deeply involved in domestic medical and life science research, and in 2005 he was appointed as Chairman of the Singapore Bioimaging Consortium. Professor Radda's invitation is thought to reflect the policy focus at the time.

45 Currently, no programs have been confirmed as directly carrying on this program. Similar programs include NUS (for medicine, materials science, and mathematics), the Lee Kuan Yew Centennial Fund, and the Singapore Mathematical Society (records are until 2019, https://sms.math.nus.edu.sg/index.php/dvp/), etc.

The Visiting Investigatorship Programme (VIP) is A*STAR's researcher invitation program. The Science and Engineering Research Council (SERC), with the aim of raising the level of domestic research, invites top researchers from abroad in fields that are likely to become global mainstream research themes. As of March 2023, the following five researchers are conducting research in Singapore under the A*STAR program: Thomas C. Südhof (Stanford University), Tomaso Poggio (MIT), Pauline M. Rudd (University College Cork APC Microbiome Ireland), Gregory L. Verdine (Harvard University), and Zhao Huimin (University of Illinois at Urbana-Champaign).[46]

Furthermore, research and development in quantum technologies, one of the most advanced fields in science, is being promoted by inviting top talent from developed countries. In 2007, Centres of Excellence were established within NUS in the fields of quantum metrology and sensing, quantum computing, and quantum materials, with researchers from abroad being appointed as leaders: Vlatko Vedral (retired in the summer of 2022), A.K. Ekert, and A.H. Castro-Neto.[47]

3.5 Primary Measures Related to Attracting International Students

3.5.1 Basic Information

As a human resources hub in Asia, Singapore actively accepts international students, not only for science and technology human resources, but also for all educational courses from elementary to high school. This section provides an overview of the trends in higher education in particular.

In higher education, in addition to the six autonomous universities, five schools in North America (MIT, JHU, Georgia Institute of Technology, University of Chicago Booth School of Business, and Wharton School of the University of Pennsylvania) and INSEAD in France have a strong presence and are actively accepting students. There are also double degree programs such as Yale-NUS College and Duke-NUS Medical School. However, it has already been announced that the Yale-NUS College program will end in 2025[48] and that it will be integrated into NUS's own University Scholars Programme.

International students who wish to study full-time must obtain a student visa (Student's Pass) before entering Singapore.

46 A*STAR website. https://www.a-star.edu.sg/Research/funding-opportunities/visiting-investigatorship-programme/visiting-investigators

47 For details, including each individual's research activities, refer to Chapter 6 of the APRC research report "Quantum Technology Trends in Major Countries and Territories in the Asia-Pacific Region" from 2022.

48 "Yale-NUS College" was a program that provided a liberal arts education in collaboration with Yale University. An MOU was signed in 2010, and the first 157 new students were enrolled in August 2013. However, the end of the program was announced in July 2021 in the Yale Daily News and via an NUS press release (https://yaledailynews.com/blog/2022/05/27/yale-nus-announces-closure-by-2025-new-college-takes-its-place/). New student recruitment was suspended in August 2021, and it was confirmed that the program had ended ("Timeline of Yale-NUS College," Straits Times, August 27, 2021).
There has been a variety of speculation on the reasons for why the program ended, including NUS's intention to provide its own liberal arts education and the high cost of maintaining the program ("What's behind the decision to close Yale-NUS College?," Straits Times, September 5, 2021).
In Singapore, the end of the program was reported in the Straits Times in August. https://www.straitstimes.com/singapore/parenting-education/yale-nus-to-stop-taking-in-new-students-as-part-of-nus-plans-for-a-new

Scholarship System for International Students

As was already mentioned in section 3.2.2, A*STAR provides systems for international graduate students. This section introduces the systems for international undergraduate students.

ASEAN Scholarships is a system that was established for the purpose of attracting outstanding international students from ASEAN member states.[49] It is aimed at young people from ASEAN countries who have achieved outstanding results at the GCE A Level[50] (exam fees will be covered by the scholarship only once), and, in 2023, the program will be opened to all ASEAN member states (excluding Singapore, which is the host country).

ASEAN Undergraduate Scholarships is a system that supports study for particularly talented international students from ASEAN member countries. The program is limited to students who will enroll in NUS or NTU, and each university has detailed application requirements.

The Dr. Goh Keng Swee Scholarships[51] are private scholarships that are provided by the Association of Banks in Singapore. Named after Goh Keng Swee, who served as the bank's former vice president (1973 to 1985), the scholarships support particularly outstanding international students from 15 Asia-Pacific countries and regions, including Japan and South Korea. Of the students enrolling in the four autonomous universities of NUS, NTU, SMU, and SUTD, three to four students are selected each year and receive support for tuition, living expenses, and travel expenses, etc. for up to four years.

3.6 Other Institutions and Policy Measures

This section introduces educational systems, awareness programs, and labor market policies that are related to nurturing and securing science and technology human resources to the extent that they are relevant to the purposes of this report.

3.6.1 Educational Reforms and an Emphasis on "Thinking Ability and Creativity"

Singapore is the only country with a score of 6 in "Quality of Science and Mathematics Education" ranking first in an index comparing the academic standards of 25 countries in the Asia-Pacific region, Singapore's average PISA score was 569 points in 2018, and the country also has high "Proficiency in Reading and Arithmetic in Primary Education," all of which place Singapore at the top of the list, indicating an internationally noteworthy trend in human resource development in general. On the other hand, it has been pointed out that this has the negative effect of society placing excessive emphasis on academic ability and academic background.

There are two major visions for the direction of science education in Singapore today. The first is the TSLN (Teaching Schools, Learning Nation) concept[52] that was announced by then-Prime Minister Goh Chok Tong in a

[49] Refer to the relevant page on the MOE website. https://www.moe.gov.sg/financial-matters/awards-scholarships/asean-scholarships

[50] The GCE is a university entrance qualification in the UK and is recognized by many universities around the world. A-levels are the most common university entry qualification. Refer also note 57.

[51] Refer to the Association of Banks in Singapore website. https://www.abs.org.sg/dr-goh-keng-swee-scholarship

[52] Infopedia article on the "Thinking Schools, Learning Nation (TSLN)" concept (last accessed on April 20, 2023) https://eresources.nlb.gov.sg/infopedia/articles/SIP_2018-06-04_154236.html

speech on June 2, 1997, and marked a shift towards education that emphasizes thinking ability and creativity by carefully selecting the knowledge content to be taught will maintaining academic standards. The other is the TLLM (Teach Less, Learn More) concept[53] that was presented by current Prime Minister Lee Hsien-Loong in his National Day speech in 2004; while sharing the same ideals as the TSLN concept, it provides guidelines for education that does not place undue emphasis on academic achievement.

Singapore has adopted a 6-4-2 system (6 years of primary school, 4 years of secondary school, and 2 years of junior college) that is modeled after the education system of Great Britian, its former colonial power. After graduating from secondary school, students go into junior college as a pre-college course and as a preparatory stage for a four-year university, or a polytechnic course to acquire skills for practical work in the industry.[54] The "project work" included in the junior college curriculum incorporates "inquiry-based learning," in which scientific knowledge is applied to problems that arise in the real world.[55] NUS, Singapore's top national university, also has an affiliated high school of science and mathematics; in addition to providing practical educational programs in collaboration with industry, in recent years the high school has announced high school-university collaborations for developmental education with affiliated higher education institutions such as the NUS College of Design and Engineering.[56]

3.6.2 Spreading Science to Society Through Education

In relation to the previous section, parents in Singapore are generally said to be actively involved in their children's science, technology, and mathematics (STEM) education. The Science Centre of Singapore (SSC) is also involved in spreading scientific knowledge amongst young people.

The Young Scientist Badge Scheme, which the Centre has been developing since 1982, aims to (1) arouse curiosity about science amongst young people, (2) encourage independent learning in various fields of science, and (3) provide opportunities to develop independence and creativity.[57] In the scheme, elementary school students engage in activities such as exploring specific science topics and conducting science and technology experiments, and then earn badges based on their level of achievement. To date, the Centre has distributed over one million badges to Singaporeans, and, on its 40th anniversary, three new types of badges were added to the existing 22 types. It can be inferred that these projects have made scientific inquiry familiar to children from an early age and have fostered it as a kind of national culture.

[53] Ikeda (2006) was also referred to for background information on and evaluations of TSLN and TLLM.

[54] Refer to the Singapore Examinations and Assessment Board website (https://www.seab.gov.sg/). Students in Singapore are assigned to the Express (E), Normal (Academic), or Normal (Technical) courses based on their performance in the Primary School Leaving Examination (PSLE). To proceed on to university, students must then take the General Certificate of Education (GCE) exam at the appropriate level for each course. Students who enter the Integrated Programme, which is for particularly outstanding academic performance even amongst Express students, take exams at the end of their sixth year to obtain A-Level (13 schools) IBDP (3 schools) or a special diploma from that school (1 school).

[55] Japan Gender Equality Bureau Cabinet Office (2015) "Singapore," *Comparative Analytical Research Report on Social Systems and Human Resource Development in Related Countries with the Aim of Promoting Women's Active Participation in Science and Engineering Fields,* p.150. https://www.gender.go.jp/research/kenkyu/pdf/riko_comp_03_05.pdf

[56] Refer to the September 27, 2022 press release from NUS High School of Math & Science. https://www.nushigh.edu.sg/news-n-events/recent-highlights/press-release-strengthening-partnerships-with-industry-and-ihls-appointment-of-new-chairman-to-board-of-governors

[57] Refer to the SSC official website and the overview of the YSB scheme. https://www.science.edu.sg/for-schools/resources/young-scientist-badge-scheme

The Centre also operates “STEM Inc,” a developmental education program for secondary education.[58] This abbreviation combines STEM with “innovation (in)” and “creativity (c)” to help produce future scientists and engineers, and, with support from the MOE, is implementing the Applied Learning Programme (ALP) and the Industrial Partnership Programme (IPP), which provides opportunities for early exposure to real-world industry.

3.6.3 Expanding Employment for Highly Skilled Human Resources

With the “Smart Nation” concept proposed in 2014, Singapore has embarked on a full-scale national digital transformation (DX) initiative. As a leader in this effort, Singapore is working to nurture and maintain human resources who can identify the value of data and use it appropriately. RIE2025 also includes a section on the digital economy, envisioning and institutionalizing the establishment of doctoral programs in the fields of applied engineering and AI (previously mentioned in sections 3.2.5 and 3.2.6). In the global competitiveness rankings by the Swiss business school International Institute for Management Development (IMD), Singapore has consistently been in the top five in “digital competitiveness” since 2018 and maintains the top position in the Asia-Pacific region.

In recent years, Singapore has made it clear that it is focusing on human resource development in the digital field,[59] and has long had a policy of making it easier for people with advanced specialized knowledge and skills to obtain residency and work permits. Usually, employment passes (EPs) are obtained by researchers, technicians, and other professionals,[60] but a number of new measures have been introduced in recent years.

On August 29, 2022, Singapore’s Ministry of Manpower (MOM), Ministry of Trade & Industry, and Ministry of Communications and Information announced a new employment permit/ONE Pass (Overseas Networks and Expertise Pass) for highly skilled international human resources, which allows them to work for multiple companies.[61] ONE Pass will be introduced from January 1, 2023. Previously, Singapore has also issued the Tech Pass to international personnel with a monthly salary of $20,000 SGD (approximately 2 million JPY) or more who are employed by tech companies, thereby allowing highly skilled personnel to enter and work in Singapore. The ONE Pass that is being introduced this time is targeted at international talent with a monthly salary of $30,000 SGD (approximately 3 million JPY) or more, or those who have outstanding achievements in the arts, culture, science and technology, research, or academia. Compared to the existing EP, ONE Pass is narrower, targeting only the top 5% of earners, but allows for greater operational flexibility by allowing foreign nationals to work without being restricted to a single corporate position.

58 Refer to the “STEM Inc” website by the Science Centre of Singapore. https://www.science.edu.sg/stem-inc/about-us/about-stem-inc

59 SPAP Basic Materials Collection. https://spap.jst.go.jp/resource/pdf/aprc-fy2022-pd-sgp01.pdf#page=37

60 Ministry of Education, Culture, Sports, Science and Technology, “3.1.4: Characteristics and Initiatives in Other Countries / Singapore” “Report on Survey of International Standards for Funding the Acquisition of Human Resources” https://www.mext.go.jp/b_menu/shingi/kokurituken/gijiroku/__icsFiles/afieldfile/2016/08/15/1375576_05.pdf#page=92

61 Refer to the Ministry of Manpower (MOM) press release, JETRO business brief. (https://www.jetro.go.jp/biznews/2022/09/b418e2cb02af73e5.html), and Nikkei Asia report data August 29, 2022, etc. (https://asia.nikkei.com/Economy/Singapore-offers-new-elite-visa-as-global-talent-hunt-heats-up).

Table 3-4: COMPASS Scoring Criteria

	Individual Attributes	Company Attributes
Foundational Criteria	**C1: Monthly Salary** Relative to local PMET salary norms for sector	**C3: Diversity** Whether candidate improves national diversity in company
	C2: Educational Background Based on candidate's qualifications	**C4: Support for Local Employment** Based on local PMET share relative to industry peers
Bonus Criteria	**C5: Skill Bonus** For candidates in a job where skill shortages exist	**C6: Strategic Economic Priorities Bonus** For partnership with Government on ambitious investment, innovation, internationalization, or company and workforce transformation activities

PMET is an abbreviation for "Professionals, Managers, Executives and Technicians."
Source: Created by the authors with reference to the Singapore Ministry of Manpower website.

The Ministry of Manpower has also announced the introduction of the Complementarity Assessment Framework (COMPASS) that will be applied from September 1, 2023.[62] Under this system, when an individual applies for a work visa, both the individual and company are evaluated under on a point system based on the six attributes listed in Table 3-4, and a work visa is issued only if a total of 40 points or more are allotted. Countries such as the United Kingdom and Germany in Europe and Thailand in Asia are already successively issuing visas for highly skilled professionals, and this series of measures can be said to be Singapore's first step in preparation for the intensifying global competition to acquire highly skilled human resources.

Additionally, like other developed countries, human resource development through recurrent education is thriving in response to new industries that are emerging through the social implementation of science and technology. SkillsFuture, a vocational training program led by the Ministry of Manpower, announced in April 2020 that it would strengthen career transition support measures for mid-career workers and that it will continue to do so in 2022. In the ICT field, a framework known as the TechSkills Accelerator has been established, with the Infocomm Media Development Authority playing a central role, and is working with Workforce Singapore and the National Trades Union Congress to developed highly skilled digital human resources.[63]

In the ICT field, which has been expanding in recent years, progress has been made not only in retraining specialized personnel, but also in nurturing new human resources (as well as the inclusion of non-specialized personnel). According to GovInsider, 54% of companies in Singapore replied that a challenge to succeeding at DX is a "lack of understanding and knowledge of digital tools among employees," and that only 35% of companies are "capable of adopting more advanced tools" such as AI, data analysis, and IoT.[64] In order to solve this talent

[62] Refer to the Ministry of Manpower website. https://www.mom.gov.sg/passes-and-permits/employment-pass/upcoming-changes-to-employment-pass-eligibility/complementarity-assessment-framework-compass

[63] For the full story, refer to the SkillsFuture website (https://www.skillsfuture.gov.sg/), and for 2022 budget trends refer to Budget 2022 (https://www.ssg-wsg.gov.sg/budget2022.html)

[64] "New Temasek-based firm aims to address Singapore's digital talent gap," GovInsider article dated November 8, 2022. https://govinsider.asia/digital-economy/new-temasek-based-firm-aims-to-address-singapores-digital-talent-gap/

gap, Temasek, a state-owned Singaporean company, collaborated with the Indian branch of the United States IT company UST to launch "Temus" (a compound of the names of both Temasek and UST) and in April 2021 began the "Step IT Up×Temus" project.

Temus is a company with operations in Singapore and Vietnam that promotes and supports the digital transformation of government agencies and companies by providing services such as presenting, designing, and building digital solutions. The "Step IT Up×Temus" project is based on past practices in Western countries and transplants those best practices to Singapore, and consists of a course where workers are (1) reskilled in the digital field in a short period of four to six months, (2) engaged in projects under the supervision of professional mentors, and then companies are encouraged to (3) hire them as company employees and bring them into industry as human resources.[65]

In the second half of 2022, many global IT firms, mainly in the United States, made large-scale layoffs of tech personnel in response to the worsening economic situation due to sluggish growth in digital demand amidst the spread of the COVID-19 pandemic, and approximately 1,300 individuals in Singapore were also affected. In response, the government of Singapore is working to transform these human resources through the aforementioned Step IT Up×Temus project, launched a new project called "Tech for Public Good" from November 2022 to meet labor demands in the public sector, and is working to secure outstanding human resources who will work on solving issues with public services. More recently, based on the "Deep Tech Talent Central" initiative announced on January 13, 2023, the government set forth a goal of training at least 900 people by 2025 to work in deep-tech fields such as biotechnology, artificial intelligence, and quantum technology.

In these ways, science and technology human resources have continuously been positioned as players responsible for promoting the government's DX initiatives. The expansion of the deep-tech sector is not only utilizing existing human resources, but by providing vocational training opportunities to individuals with no experience in digital fields and aiming to have them change employment, it suggests that Singapore is enhancing the labor supply in a comprehensive manner and strengthening its scientific and technological capabilities.[66]

Nurturing and Maintaining Female Researchers

In light of shrinking working-age population, encouraging women's participation in science and technology, also known as "gender mainstreaming," is important not only from the perspective of equal opportunity, but is also a highly effective measure from the perspective of promoting science and technology. In a previous survey[67] conducted by the Japan's Gender Equality Bureau in the Cabinet Office, Singapore and South Korea were cited as examples of foreign countries in the Asia-Pacific region, along with Scandinavian and Western European countries, suggesting that both countries should be focused on as good examples. In particular, the percentage of female researchers in Singapore surpasses that of Korea and Japan, and stands out among Southeast Asian countries. This report hopes to expand on the points made in the Cabinet Office survey and examine the specific factors behind

65 Refer to the Step IT Up×Temus website. https://www.stepitup.temus.com/

66 Job mobility induced by value-added demand in growing industrial sectors is defined by economist Hisashi Yamada as "demand-pull" labor mobility, which he sees as a factor contributing to economic revitalization. (Yamada [2016] "Employment Mobility Without Unemployment," Keio University Press, p.60). Although it is necessary to take into consideration the strength of state power and differences in employment laws and regulations that would make a transformation possible in a short period of time, the ongoing employment expansion measures in Singapore can also be said to be an example of contributing to the revitalization of the deep tech field.

67 https://www.gender.go.jp/research/kenkyu/pdf/riko_comp_03_05.pdf

Singapore's high proportion of female researchers.

As can be seen from Figure 3-3,[68] in Singapore both the actual number and the proportion (male/female ratio) of female researchers have consistently increased over the five years since 2015. While the actual number of male researchers has also increased, the aforementioned increase in the proportion of female researchers means that the rate of increase for the number of female researchers is higher than that for male researchers, which is considered to be indicative of their active entry into R&D positions.

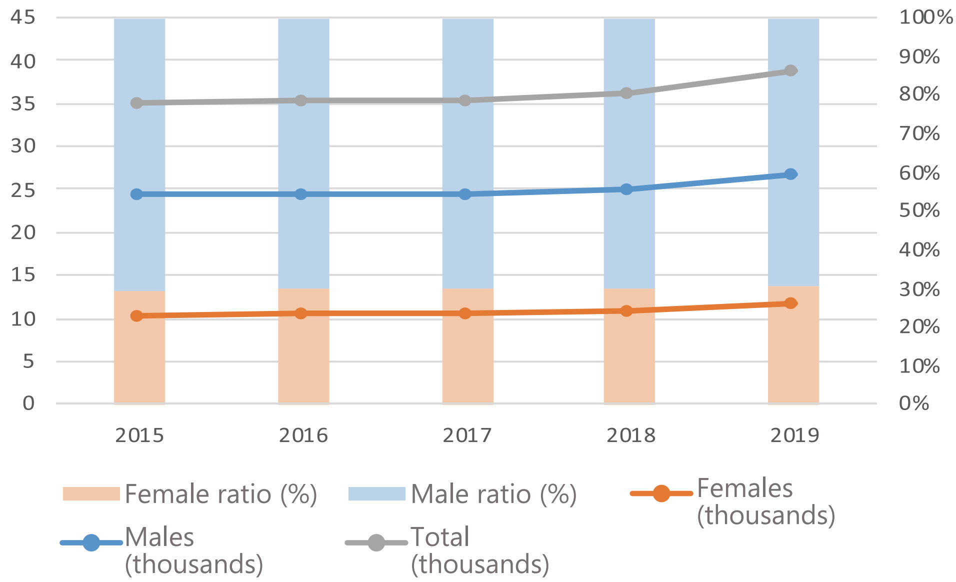

Figure 3-3: Change in Number of Researchers and Male to Female Ratio

Source: Singapore Ministry of Social and Family Development website

Why is the proportion of female researchers in Singapore so high? This report believes that it is mainly due to the following factors.

First is the active involvement of both parents in STEM education. A motivating factor for this can be inferred to be the influence of educational reforms grounded in a new view of academic achievement, such as those mentioned in this section, which are based on an education system that was high performing to begin with. The foundation for such an enhanced educational system, including home education, can be attributed to the existence of excellent teacher education that guarantees the quality of STEM education.

Additionally, there is high demand for labor that can make use of expertise in science and technology fields.[69] This is evidenced not only by the consistent emphasis on the medical and life science fields since the 1990s, the early days of Singapore's science and technology promotion, but also by the establishment of R&D clusters in various fields (media and engineering) in the 21st century and the demand for financial engineering derived from Singapore's position as a financial center in Asia. In terms of top talent, as mentioned in 3.6.3, Singapore continues to focus on expanding the market for deep tech and the digital economy, and is further enhancing this by

[68] Refer to the statistics published by the Singapore Ministry of Social and Family Development. https://www.msf.gov.sg/research-and-data/Research-and-Statistics/Pages/Labour-Force-and-the-Economy-Research-Scientists-Engineers.aspx

[69] In addition to the examples listed below, graduates in STEM fields who receive vocational training at the Institute of Technical Education (ITE) tend to have a high employment rate.

encouraging employment transformation. It is expected that Singapore will see a continuous demand for science and technology personnel in various fields in the future.

Although not necessarily directly related to science and technology, Singapore's social environment, encourages women's advancement in society, cannot be overlooked as a background factor. Approximately 250,000 foreign maids are employed among the 1.7 million households in Singapore, and these maids enable women to continue developing their careers even during childbirth and childcare, and are thought to contribute to the increase in the number of female researchers.

It is believed that the above factors encourage women to enter the labor market and that they naturally lead to nurturing and maintaining female researchers, even without the implementation of support measures that are specific to female researchers.

4 Evaluation and Characteristics of Singapore's Nurturing and Maintaining of Science and Technology Human Resources, and Reference Points for Japan

This section will summarize the evaluation and characteristics of Singapore's systems, as mentioned in the previous sections, and suggest reference points for Japan, which will lead to the recommendations listed in the next section.

4.1 Evaluation and Characteristics of Singapore's Nurturing and Maintaining of Science and Technology Human Resources

Section 2 compared Singapore's R&D capabilities with those of major countries (the United States, China, and Japan) in terms of number of papers and number of top 1% papers relative to GDP and R&D investment in order to provide an overview of if Singapore's R&D capabilities are commensurate with its R&D expenditures in comparison with the rest of the world. The results showed that Singapore can be evaluated as a country that produces numerous outstanding results and that it has R&D capabilities in terms of both quality (top 1% of papers) and quantity (number of papers) that are commensurate to, or even exceed, its economic power (GDP)

Furthermore, by looking at trends in foreign direct investment (FDI) over the past years (Figure 4-1), it can be seen that Singapore has a remarkably high degree of external dependence, even more so than that of other advanced economies. From the 1970s to the 1980s, Singapore was part of the so-called newly industrialized economies (NIEs) in the region and grew as a financial center in the Asia-Pacific. Under these systems, the foundations of higher education were in place, in the 1990s the Science and Technology Plan was formulated (as mentioned in section 3.1), and its promotion policies began. Based on these facts, it can be said that the development of Singapore's economy has been driven more by high levels of foreign investment and the accompanying advanced technologies and human resources from overseas than by its own scientific and technological development and achievements. Although Singapore has achieved unprecedented economic development through foreign investment, its excessive dependence on foreign capital, technology, and human resources is also a source of vulnerability. In order to mitigate this vulnerability and achieve further development, Singapore is continuously and vigorously pursuing policies to strengthen its domestic scientific and technological capabilities.

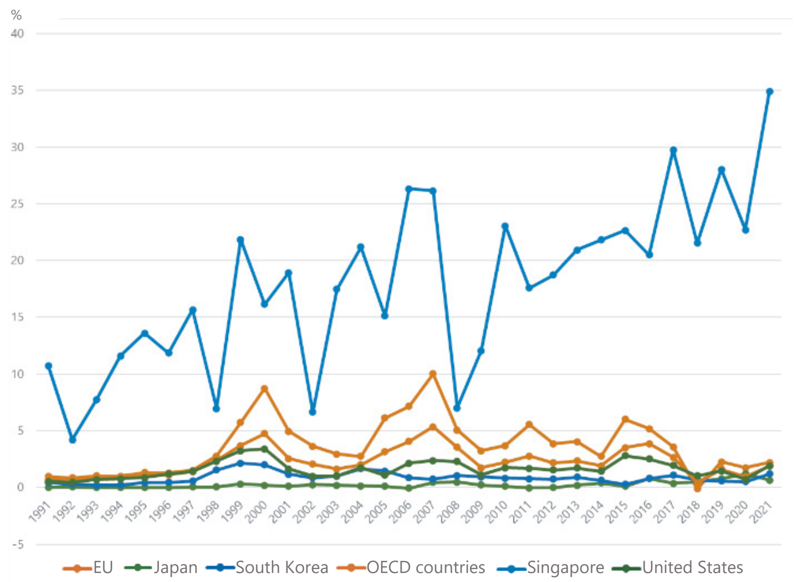

Figure 4-1: International comparison of net foreign direct investment (FDI) inflow as a percentage of GDP (1991 to 2021)
Source: Created by the authors based on data from the World Bank database (https://data.worldbank.org/)

While Singapore continues to enjoy high economic development led by foreign capital, it is also trying to further strengthen its research and development capabilities and support the country's prosperity while building stronger domestic systems. In addition, in strengthening its research and development capabilities, Singapore is naturally trying to leverage the close networks it has built up with foreign countries through the introduction of foreign capital.

Next, this section will point out the following four characteristics of Singapore in terms of nurturing and maintaining science and technology human resources, taking into account the afore-mentioned economic development structure and the involvement of science and technology in it.

1. Singapore has a high proportion of international researchers, and there is a strong tendency not to distinguish between domestic citizens and foreign nationals.
2. Singapore has a high proportion of female researchers, and there is a strong tendency not to differentiate between genders when making appointments or promotions.
3. Singapore has high mobility for science and technology human resources.
4. Singapore is home to universities that are at the top of the world university rankings for the Asia-Pacific region.

As previously mentioned in section 2.1, Singapore has active human resource exchanges with other countries in the Asia-Pacific region, and is known for the high mobility of its researchers. On the other hand, the situation where researchers move back and forth internationally without settling in at a university or research institution has drawn criticism from a variety of fields that it may lead to a drain on human resources. In fact, at the beginning of the 21st century, the policy of inviting top international human resources, primarily in the life sciences, was being spotlighted, but at the same time it allowed many researchers to move overseas.[70] Due to this historical background,

70 Refer to Iwasaki (2015) pp.63-64. Kobayashi and Tsuda's "The Science and Technology Situation in Singapore" also states that the shift to exit-oriented research has led to the departure of some big-name researchers who have not been able to retain their positions. https://www.jst.go.jp/crds/report/SG20161130.html#sec6-1

the system was revised to require scholarship recipients to conduct research at an institution within Singapore for a certain period of time after obtaining their degree.

From the perspective of an educational system that supports nurturing human resources, coincidentally, the direction of Singapore's reforms is quite similar to those launched in Japan, as has already been pointed out by a comparative educator Mitsuhiro Ikeda (Ikeda 2006, 2008). In other words, there was a shift from focusing on knowledge to emphasizing thinking skills, and respecting learning outside of academic subjects. In Singapore's case, it can be inferred that the latter, in particular, was supported by families' active involvement,[71] which in many ways led to the development of more advanced academic abilities while maintaining basic academic abilities.

It is also important to highlight the presence of NUS as Singapore's hub for producing high-caliber science and technology talent. As detailed in section 1.6, NUS is ranked 11th in both the QS and THE world university rankings as of March 2023, and has maintained the highest ranking in the Asia-Pacific region five consecutive years since 2018. Also, a reason behind Singapore's rapid progress was inferred due to enhancing "internationality," including through English education, and the establishment of research centers that meet industry needs. This is in line with the shift in pragmatic science and technology promotion policy since 2010. On the other hand, it is important to note that this trend means a relative weakness in the promotion of basic research, and it remains to be seen whether NUS will continue to be a leader in the development of science and technology in the Asia-Pacific region.

4.2 Reference Points for Japan in Promoting Nurturing and Maintaining Science and Technology Human Resources

Based on 4.1, the following points are considered to be issues for which Japan should refer to Singapore's policies and strategies.

1. Steady (sustained) expansion of investment in R&D activities (expanding national R&D expenditures).
2. In the global competition for human resources, take no measures to systemically distinguish between domestic citizens and foreign nationals.
3. Avoid taking overly defensive measures against knowledge loss.
4. Flexibly develop potential human resources in science and technology.

For the first and second points, relevant key data and key measures for Singapore and Japan are compared and listed in Table 4-1. In terms of the total number of papers and the number of highly cited papers (adjusted number of top 10% papers), which are indicators of scientific research capability, a contrast can be seen between the stable growth in Singapore and the slowdown in the growth rate in Japan.[72] Additionally, the number of patent applications, which is an indicator of technological strength, in Singapore the number of patent applications has more than doubled in the past 10 years due to the establishment of numerous intellectual property-related

[71] A 2015 survey by Japan's Gender Equality Bureau in the Cabinet Office noted Singapore's high level of interest in STEM education among parents, and pointed out that Singapore is characterized by the provision of specialized tutors and parent support groups that develop their own plans (Cabinet Office 2015, pp.149-150).

[72] Ministry of Education, Culture, Sports, Science and Technology / National Institute of Science and Technology Policy, "Japanese Science and Technology Indicators 2021" (https://www.nistep.go.jp/sti_indicator/2021/RM311_42.html) and "Japanese Science and Technology Indicators 2022" (https://www.nistep.go.jp/sti_indicator/2022/RM318_42.html)

departments within NUS and the approval of intellectual property ownership by the researchers themselves. As mentioned in 1, Japan has remained at a consistently high level for the past 20 years, but there has also been no particular increase in Japan's number of patent applications.

Table 4-1: Comparison of major scientific research capabilities between Singapore and Japan

	Singapore	Japan
Research capability indicator: Number of papers and number of highly cited papers	Globally: 25th+, 25th+ Globally: 18th, 18th	Globally: 4th (-), 5th (-) Globally: 18th, 18th
Technological capability indicator: Patents	Number of registrations has approximately doubled in the past 10 years	Remains at a high level of global share
Research and development expenditures	For the past 10 years, R&D expenditures has been maintained at around 2% of GDP, with R&D expenditures of approximately $80 million USD	3rd place, same as in the previous year; 4th place, same as in the previous year if focus is only on universities
Number of researchers	Proportion of foreign national has increased by 2.5 times compared to 2009. There are increasing number of individuals who hold a master' s degree in the private sector and who hold a PhD in the public sector	3rd place, same as in the previous year (est. to be 4th place, same as in the previous year if focus is only on universities)

Source: Created by the authors

With regard to the second point, most of the scholarships and grants provided by the NRF and A*STAR do not distinguish between domestic and international applications, and this characteristic of newly establish systems also remain the same. As an exception, there is a research grant program (refer to 3.2.4) by the Ministry of Education that is limited to Singaporean citizens, but this is also limited to the autonomous universities and is presumed to be a special measure for domestic use.

For the third point, the more the mobility of human resources increases, the more there are concerns about the loss/outflow of critical technologies that could threaten national security, and as such in recent years many countries and regions have taken explicit measures from that perspective. Singapore in particular is heavily dependent on foreign countries for human resources as well as for financial capital. As such there are always concerns of brain drain, and if foreign countries adopt policies that suspend the flow of human resources then Singapore's means of obtaining human resources will be lost. However, Singapore seems so far to be generally tolerant of human resource mobility and the risk of losing key technologies, as is evidenced by the fact that it continues to exchange talents with both the United States and China.

Historically, since the late 1970s, the United States has provided abundant scholarship funds from the federal government and has attracted many foreign students. However, the federal government's stance that "the promotion of basic research fosters domestic applied industries and contributes to America's national interests" indicates that it invests national funds in human resource development that does not necessarily contribute to the country's economic growth, and the United States government faced public criticism in the 1980s as Japan and other emerging economies caught up in applied industries.[73]

Based on this past experience, the United States has often taken a cautious stance towards outflows of scientific knowledge. On the other hand, the growing tensions between the United States and China since the 2010s, including economic frictions, have led to a number of issues such as the already cancelled China Initiative,[74] and can be understood as an overreaction to economic security concerns about the exodus of scientific knowledge that leads to critical technologies, leading to a move away from the United States by highly skilled Chinese human resources. Under these circumstances, it is important for science and technology development that a country maintain an environment that smoothly accepts highly skilled human resources without excessively closing the door to foreign countries. From this perspective, Singapore's response can be of great use to Japan.

In terms of the fourth point, in Japan, which is confronted with a rapidly falling birthrate and aging population for which there are no global precedents and in consideration of the fact that its potential major sources of science and technology human resources are overseas human resources and female researchers, the following measures will be crucial.

(1) Maintaining highly skilled international human resources

Although demand for IT personnel is temporarily sluggish, in the long term, international demand is expected to exceed supply. Singapore's work visa system for international IT talent is a flexible response depending on the science and technology field. Japan will also launch a new system starting in FY2023 for highly specialized workers with annual incomes of 20 million JPY or more, but Singapore's system is more flexible, and it should be used as a reference for considering the pros and cons of introducing such a system to Japan after examining its merits and demerits.

(2) Maintaining female researchers

Singapore has an remarkably high proportion of female researchers, and it can be inferred that this is due to (1) high educational standards for women and comprehensive STEM education, and (2) a domestic environment that supports women's social advancement in all industries and fields, including in research and development. In order to maintain research and development human resources in Japan, it is essential for women to make further advances in these fields. To achieve this, Japan must continue to take measures and use Singapore's well-developed systems and initiatives (mentioned in section 3.6.4) as a reference.

(3) Implementing human resource recall programs

One of the reasons why Japanese students and researchers do not take on the challenge of going abroad is that

[73] Takahiro, Ueyama (2010) "Beyond Academic Capitalism: The Current State of American Universities and Scientific Research," NTT Publishing, pp.205-309.

[74] There are a variety of reports about this topic, but refer to the following for a comprehensive summary from scientific and technological perspectives. Eisuki, Enoki, "The American Government has Apologized -- Japan's Strange Situation Where the 'Thousand Talents Plan' and the 'China Initiative' are Continuing," Yahoo! News article dated December 10, 2022. https://news.yahoo.co.jp/byline/enokieisuke/20221210-00327574

the number of tenure positions for university professors and other positions has been reduced in Japan, which means that challenging oneself in this way does not necessarily contribute to career development in Japan. The fundamental solution, of course, is to increase the number of tenure positions for Japanese researchers through university funds and other means. However, in addition to this solution, when taking measures to nurture and maintain human resources Japan should also refer to “human resource recall programs” such as the one in Singapore.

As mentioned at the beginning of 2.1, Singapore is a city-state. Studies on urban innovation that compare Singapore with Seoul point out that the promotion of science and technology, which contributes to the development of knowledge-intensive industries, goes beyond mere infrastructure support and financial assistance, and that it is also effective to have social systems that accommodate diverse players and allow feedback for policy cooperation (Hartley et al. 2018, p. 608). This kind of “system flexibility” is a point that is consistent with the four reference points, and Japan should pay close attention to it.

5 Summary and Recommendations

Singapore has been highly visible in the Asia-Pacific region in terms of its scientific and technological innovation outputs, including research papers and patents. In recent years, Singapore has also been strongly oriented toward collaborations with industry, and the National University of Singapore, the country's top university, has maintained its top position in the Asia-Pacific region in various world university rankings. Behind this trend are not only strong initiatives such as the establishment of R&D clusters that select top foreign researchers, but also ongoing efforts to actively take in foreign nationals and efforts to nurture and maintain female researchers.

As Japan seeks to improve its scientific research capabilities in the face of rapid population decline, there are many points of reference that it can draw from Singapore's practices. A prerequisite for this is steady (sustainable) funding, particularly for research and development. Additionally, in order to make the research environment open to foreign nationals, it should not systemically distinguish between domestic citizens and foreign nationals, and it is also important to ensure openness by not taking excessively defensive measures against the risk of knowledge leaks. Furthermore, it is important to have flexibility in developing potential sources of science and technology human resources, such as promoting women's active participation and inviting back Japanese nationals who are living overseas.

An international joint research project led by the National University of Singapore is currently underway to examine the impact of COVID-19 on the trend of foreign students in the Asia-Pacific region.[75] Although the research is ongoing and the results have not yet been published, Singapore's high level of interest in human resource development and recruitment can be seen in the fact that it is taking the initiative in conducting research on this global issue.

Nurturing and securing science and technology human resources will not only creates employment by utilizing talented human resources, but also leads to producing the next generation who will contribute to solving long-term issues and strengthening international relations through people-to-people exchanges. The various measures taken by Singapore as described in section 4.2 should be referred to by all sectors in promoting the nurturing and securing of science and technology human resources in Japan. Additionally, in promoting science and technology cooperation with Singapore, Japan should continue to track research trends in Singapore in nurturing and securing human resources not only as a country covered that was by this report, but also on a regular basis going forward.

[75] "International Student Mobility in a Time of Pandemic: Regimes, Experiences, and Aspirations" https://covidismstudy.wordpress.com/

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