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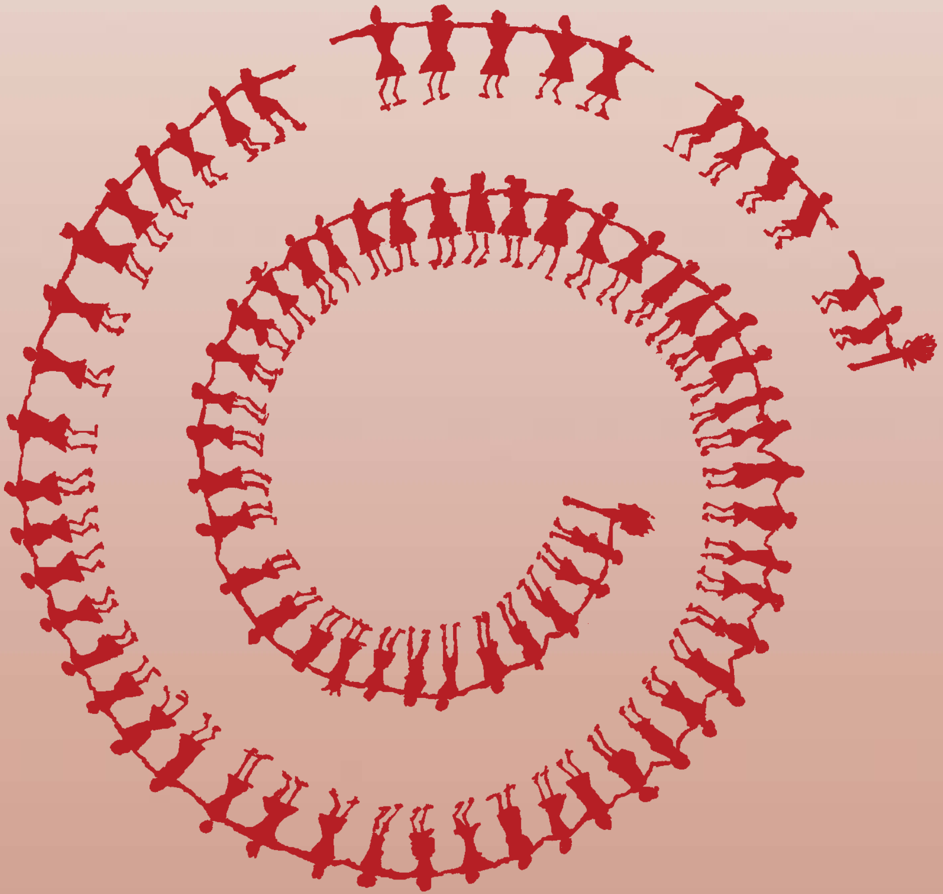
Report No. 57

South Asia Human Development Sector

International Comparative Study: Engineering Education in India

April 2013



Discussion Paper Series

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Acknowledgments

The study on which this report is based has been led by Hiroshi Saeki and Saori Imaizumi. The report has been prepared by collecting data on Brazil, China, India, Japan, the Russian Federation, the United Kingdom, and the United States.

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Executive Summary

The government of India and state governments there have undertaken reforms in higher education. In particular, the engineering education sector has launched reform initiatives within the current legislative framework through the Technical Education Quality Improvement Program (TEQIP). Participating institutions have been selected through a norm-based funding mechanism after meeting criteria for the reforms, which promote, for instance, autonomy, the decentralization of the financial framework, the establishment of a functioning board of governors, and the strengthening of partnerships with the private sector. The working group report on technical education for the government's 12th Five Year Plan also proposes ambitious, but feasible reforms in the sector that, over the 10 years, involve, for example, increasing the number of PhD students by 10-fold and the number of faculty members many times over, while encouraging more autonomy in colleges by relying less on the affiliation system (MHRD 2011a).

Given this dynamic momentum in engineering education in India, the sector is expected to receive a significant boost over the next few years. It is therefore timely to assess the position of the sector in India within the international context. This study aims to provide the Ministry of Human Resource Development (MHRD), the All India Council for Technical Education (AICTE), and relevant stakeholders with key facts, reliable data, and international comparisons to establish a common ground and benchmark for the current engineering education system. Thus, the study is not intended to supply concrete policy recommendations, but, rather, to serve as a foundation to promote discussions on education in engineering. The government–World Bank team selected Japan, the United Kingdom, and the United States from among the members of the Organisation for Economic Co-operation and Development (OECD), as well as Brazil, the Russian Federation, India, and China (the BRICs) for comparative purposes for this study.

Using the latest data on each country (mostly from 2011), the study presents an analysis of the institutions, students, faculty, education outputs, and research and commercialization outputs in engineering education in India. It focuses on institutions providing engineering education and offering at least bachelor's degrees or above, while excluding polytechnics.

Because the study takes a snapshot of education in engineering without examining the evolution of the sector, the result does not necessarily reflect all the efforts of the government of India in engineering education. However, the commitment of the MHRD and the states has clearly generated major improvements, especially in the area of publishing.

Altogether, the five major findings presented here may serve as the basis for discussions among policy makers and stakeholders to make concrete and optimal policy interventions in the sector in the future.

The first finding involves the large number of engineering institutions in India. The number more than doubled within only five years, from 1,500 in 2006 to 3,400 in 2011, mainly because of the increase in the number of private institutions. Even in China, the number of institutions offering engineering degrees is only 570. These 3,400 Indian institutions accommodate 1.5 million future Indian engineers. The mushrooming engineering institutions in India have resulted in a low number of students and faculty per institution: 450 and 20, respectively. This finding supports the approach of the 12th Five Year Plan, whereby the expansion of existing engineering institutions is a priority over the creation of new institutions.

Second, the total number of engineering students in India exceeds 1.5 million, which is about the same as Brazil; these two countries are behind only China in the total number of students. Moreover, the proportion of students in higher education in India who are studying engineering is similar to the corresponding proportions in the other countries studied (though higher than the proportions in the United Kingdom or the United States). However, there are only 1,290 engineering students per million population in India, which is the lowest such ratio among the countries examined in this study. Given that industries in India are demanding more engineers (including more with enhanced qualifications), improved access to engineering education is required. Policy makers may need to consider ways to keep the number of engineering institutions at least constant, while strengthening the enrollment capacity of these institutions.

Third, the percentage of faculty with PhDs is low in India. Although there are no official data available on faculty in India, institutions participating in the Second Phase of the Technical Education Quality Improvement Program (TEQIP-II) in Andhra Pradesh show that only about 20 percent of full-time faculty hold PhDs, which is the lowest among the countries in the comparison. Given that Andhra Pradesh is one of the most advanced states in engineering education and that the institutions participating in the TEQIP-II are highly selective, the country average is most likely much less. Poor faculty qualification stems from the low number of students pursuing PhDs. The share of engineering students with PhDs among all engineering students is less than 1 percent in India. The low number of faculty with PhDs is one of the obstacles to improving the research capacity of the country. Policy makers would need to consider both enhancing the qualifications of current faculty, most of whom have only master's or bachelor's degrees, while incentivizing current students to pursue PhD degrees in engineering. Although not specifically aiming at education in engineering, the 12th Five Year Plan seeks to increase the country's enrollment capacity by another 10 million, among whom 5.7 million are to be enrolled through the accelerated expansion of postgraduate and doctoral programs. This demonstrates that the direction of policy is following the findings.

Fourth, there are limited reliable information resources available on education in engineering. This makes it difficult for policy makers, researchers, and stakeholders to conduct robust and meaningful analysis of the engineering education system. Establishing a comprehensive management information system in engineering education is indispensable if policy makers are to make strategic and evidence-based decisions. Indeed, the 12th Five Year Plan concurs with this view in that it emphasizes the importance of participation in international surveys and evaluations to compare Indian higher education globally.

Fifth, research outcomes in India, including research papers, research reference citations, and patents, have been improving and increasing in number despite the shortage of faculty with PhDs. However, the absolute number remains low. In particular, the number of patents originating in India is the lowest among the countries in the comparison. This seems to reflect the want of university-industry partnerships in the country. The 12th Five Year Plan expresses this lack by highlighting that, within the context of the plan, a focus will be on research that is linked to the national development agenda. The plan seeks to undertake a systematic approach to strengthening the scale and scope of the partnership between academia and industry. The plan also acknowledges the importance of international research collaboration.

Acronyms and Abbreviations

ABET	Accreditation Board for Engineering and Technology (United States)
AICTE	All India Council for Technical Education (India)
ASEE	American Society for Engineering Education (United States)
BRIC	Brazil, the Russian Federation, India, and China
CAPES	Coordination for Enhancement of Higher Education Personnel (Brazil)
CNI	National Confederation of Industry (Brazil)
DWPI	Derwent World Patents Index
GER	Gross Enrollment Ratio
HESA	Higher Education Statistics Agency (United Kingdom)
ISCED	International Standard Classification of Education
MEXT	Ministry of Education, Culture, Sports, Science, and Technology (Japan)
MHRD	Ministry of Human Resource Development (India)
NAE	National Academy of Engineering (United States)
OECD	Organisation for Economic Co-operation and Development
OSTP	Office of Science and Technology Policy (United States)
STEM	Science, Technology, Engineering, and Mathematics
TEQIP	Technical Education Quality Improvement Program (India)
UGC	University Grants Commission (India)
USE	Unified State Examination (Russian Federation)

Note: All dollar amounts are U.S. dollars ($) unless otherwise indicated.

1. Introduction

The central and state governments of India have been pursuing several reforms in the higher education sector. The main efforts so far have centered on legislative changes at the central level that are currently being considered in Parliament.[1] In engineering education, the government has already embarked on several reforms within the current legislative framework. The central and state governments are encouraging engineering institutions to take the initiative on reform through the Technical Education Quality Improvement Program (TEQIP), which is currently in the second phase (TEQIP-II).[2] Institutions willing to take on the challenges of reform are selected for the program through a norm-based funding mechanism.[3] Engineering institutions that are selected undertake to promote autonomy, decentralize the financial framework (for example, decision making on funds and generated revenues occurs at the institutional level), conduct pedagogical training, establish a functioning board of governors, and so on. The goal of these initiatives is to raise the quality of education, enhance the qualifications of faculty, increase and enhance research outputs, and, most importantly, improve educational standards and the employability of students. This will help India to accelerate the growth of the economy, develop a high-quality labor force, and reduce the skill shortages being faced in the country.

The government has exhibited other ambitious visions in India's 12th Five Year Plan (2012–17). The working group report on technical education proposes, among other initiatives, to increase the number of PhD students by 10-fold and the number of faculty members several times over (an additional 16,000 faculty members) in the country's system of institutes of technology within 10 years (MHRD 2011a). It proposes that more autonomy should be encouraged among colleges by relying less on the college affiliation system. The report also recommends that state and private engineering institutions should be upgraded and expanded.

Given this dynamic momentum, the engineering education sector in India is expected to receive a significant boost over the next few years. It is therefore timely to take stock and review the position of the sector internationally. This study thus aims to provide the Ministry of Human Resource Development (MHRD), the All India Council for Technical Education (AICTE), and relevant stakeholders with key facts, reliable data, and the results of relevant international comparisons to establish a common ground and to help in measuring the performance of the current engineering education system in India. This would help raise the quality of the public debate on this topic. The study does not seek to provide specific policy recommendations, but, rather, to serve as a foundation to promote discussion on engineering education in India. The government–World Bank team has selected countries among the members of the Organisation for Economic Co-operation and Development (OECD), as well as Brazil, the Russian Federation,

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[1] The measures include the National Accreditation Regulatory Autonomy for Higher Education Institutions Bill, the Higher Education and Research Bill, the Foreign Education Institutions Bill, and the Prohibition of Unfair Practice in Technical Educational Institutions, Medical Educational Institutions, and University Bill.

[2] A government program, TEQIP consists of three phases. It is financed jointly by the government of India and the World Bank. The total cost of the first and second phases are $315 million and $500 million, respectively. The total number of participating institutions was 127 in the first phase and is approximately 190 in the second phase. The first phase was successfully completed in 2009, and the achievement of the project objective was rated substantial by the Independent Evaluation Group of the World Bank (World Bank 2011a). The second phase is expected to be completed in 2014.

[3] This is equivalent to a competitive funding mechanism.

India, and China (the BRICs), for a comparison of basic information on engineering education. For this purpose, the government wished to select leading countries in engineering education, at least in terms of research outputs. Hence, Japan, the United Kingdom, and the United States were selected from among the OECD countries. The government also recognizes the importance of lessons that may be learned from the other BRIC countries, and these countries were therefore selected for the comparison.

This report is organized as follows. The next section briefly discusses the background of both general higher education and engineering education in India. Section 3 reviews earlier comparative studies on international engineering education. Section 4 describes the scope of the study. Section 5 explains the methodology of data collection and identifies the data sources. Section 6 outlines the analysis of the collected data and the findings. Section 7 presents conclusions. The appendixes describe the engineering education systems of the various countries examined in the study, the related challenges and opportunities, and the future policy goals in each country.

2. Sectoral Background

Higher Education in India

The higher education system in India is one of the largest in the world.[1] It has expanded exponentially since 1990. In 1990, there were 190 universities and 7,350 colleges, and the total enrollment in higher education was 4,925,000 (UGC 2012). As of 2011, there were 610 universities and 31,320 colleges with 14,624,990 enrollments (UGC 2011a).[2] India's 12th Five Year Plan is expected to continue to assign priority to the expansion of the higher education system, taking into account equity and quality, to achieve a 25 percent gross enrollment ratio (GER) at the national level by 2017.[3]

Types of Higher Education Institutions and the Related Regulations

There are seven types of higher education institutions in India: (1) central universities, (2) state universities, (3) private universities, (4) deemed-to-be universities, (5) institutions of national importance (such as the Indian Institutes of Technology), (6) institutions under a state legislature act, and (7) colleges. Table 1 describes the types of higher education institutions and the number of each.

Table 1: Types and Number of Higher Education Institutions, India, 2011

totals

Types of Institution	*Description*	*Number*
Central university	A university established or incorporated through a central act	43
State university	A university established or incorporated through a provincial or state act	289
Private university	A university established through a state or central act by a sponsoring body such as a public trust, a company registered under Section 25 of the Companies Act, 1956, or a society registered under the Societies Registration Act, 1860 or any other corresponding law in force in a state	94
Deemed-to-be university	Commonly known as a deemed university, this refers to a high-performing institution that has been so declared by the central government under Section 3 of the University Grants Commission Act, 1956	130
Institution of national importance and other institutions[a]	An institution established by act of Parliament and declared an institution of national importance	50
Institution under a state legislature act	An institution established or incorporated through a state legislature act	5
Colleges	Colleges award degrees through the universities with which they are affiliated (Agarwal 2009).	31,324
Total		31,935

Sources: MHRD 2011a; UGC 2011b.

Note: According to the 12th Five Year Plan, there were 46,430 institutions in 2011–12 (Planning Commission 2012).

a. "Other institutions" include the Indian Institutes of Science Education and Research, the National Institute of Fashion Technology, the Rajiv Gandhi Institute of Petroleum Technology, and the Jawaharlal Nehru Institute of Post-Graduate Medical Education and Research.

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[1] Higher education institutions include research institutions, as well as universities and colleges offering diplomas, certificates, and bachelor's, master's, and PhD degrees.

[2] The enrollment figure is for 2009–10.

[3] The GER in 2009–10 was 15 percent (MHRD 2011b).

Several entities are involved in the regulatory framework, including state governments, national- and state-level professional councils, and affiliating universities. In particular, the University Grants Commission (UGC) plays an important role in regulating general higher education institutions as the apex body for the establishment and coordination of standards in general higher education. The UGC established the National Assessment and Accreditation Council in 1994 to accredit general higher education institutions and evaluate the quality of institutions and programs. The council evaluates institutions and programs based on predetermined criteria through self-assessment and peer review. Accreditation is currently voluntary and valid for five years.

Engineering Education

The unprecedented expansion of the higher education system in India has arisen partly because of the substantial growth of engineering education. The number of engineering institutions doubled in merely five years, from 1,510 in 2006 to 3,390 in 2011. Accordingly, the total number of students enrolled in engineering education increased from 795,120 in 2004–05 to more than 1.5 million in 2009–10 (UGC 2004, 2011a). The main component in the significant expansion in engineering education is private institutions, which accounted for about 94 percent of engineering institutions in 2011.[4]

Types of Engineering Education Institutions and Related Regulations

In terms of types of institutions, the engineering education system follows the general higher education system (see Table 1**)**. While general higher education is regulated by the UGC, engineering institutions are regulated by the AICTE. The AICTE regulates technical education institutions involved in education in engineering and technology, architecture and town planning, management, pharmacy, applied arts and crafts, and hotel management and catering technology (AICTE 2007). The AICTE established the National Board of Accreditation to evaluate technical education institutions. Currently, accreditation is voluntary, and it lasts three to five years, depending on a satisfactory assessment outcome.

Challenges Facing India's Engineering Education System

The 12th Five Year Plan working group report on technical education emphasizes the importance of three areas: expansion, equity, and excellence (or quality) (MHRD 2011a). This selection reflects the challenges facing the sector. First, expansion implies the issue of access to engineering education. While engineering institutions and student enrollment have significantly increased in engineering education, access to engineering education remains limited. For instance, the latest available comparable figures (mostly from 2010) show that the GER in higher education in India in 2011-2012 is 17.9 percent, including open and distance learning, compared to 26 percent in Brazil and China and 76 percent in Russia.[5] Furthermore, per million population,

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[4] There were 3,393 engineering institutions in 2011, of which 3,184 were private (Sanyal 2012).

[5] See "Higher Education," Institute for Statistics, United Nations Educational, Scientific, and Cultural Organization (accessed 2012), http://www.uis.unesco.org/Education/Pages/tertiary-education.aspx. The figures represent the most recent comparable data available. The 12th Five Year Plan estimates the GER for India in 2011-2012 at 17.9 percent, including open and distance learning. This figure is based on the 18-23 age group, which is slightly different from

the number of engineering students in India, including both undergraduate and postgraduate students, is 1,290, which is the lowest rate among all the countries in our comparison.[6]

Second, like all other countries, there is unequal access in terms of gender, geography (urban versus rural residence), social groups, and household welfare. For example, in India, the inequality in household welfare is substantial: the completion rate in tertiary education, which includes engineering education, among 30–34-year-olds in the richest quintile was about 28 times higher than that among the same age-group in the poorest quintile in 2010.[7]

Finally, excellence mirrors the issue of quality, which stems from various aspects of the engineering education system. Only about 25 percent of technical graduates are suitable for employment in the offshore IT industry, and 64 percent of employers hiring fresh engineering graduates are only somewhat satisfied or worse with the quality of the new hires (NASSCOM and McKinsey 2005; Blom and Saeki 2011). The sector suffers a severe shortage in high-quality faculty. It is estimated that India produces 1,000 PhDs in engineering per year (World Bank 2010). This compares with the PhD production of 9,500 in the United States and 17,000 in China in 2010. It is widely recognized that the affiliation system often represents an impediment to overall quality development in engineering in India because affiliated colleges do not fully exercise academic, financial, and management autonomy under the system. Thus, one university has more than 600 affiliated colleges (World Bank 2011b). Because of the large number of affiliated colleges, the quality in planning, regulation, and supervision is usually not maintained by the affiliating universities. As a result, curricula are often obsolete, the skills taught are usually not matched with the demand or local needs, and the number and quality of faculty are frequently not sufficient.

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the UNESCO definition, which includes the 5-year age group starting from the official secondary school graduation age. However, the figure for India is higher as of May 2013, which is 18.65 percent, according to AICTE.

[6] The numbers in our comparison countries are Brazil, 2,648; China, 3,149; Japan, 3,791; Russia, 11,227; the United Kingdom, 2,356; and the United States, 2,570.

[7] "NSS 66th Round (July 2009–June 2010)," National Sample Survey Office, Ministry of Statistics and Program Implementation, New Delhi, http://mospi.nic.in/Mospi_New/site/inner.aspx?status=3&menu_id=31.

3. Previous Studies on International Engineering Education

While some comparative studies on general higher education have been conducted, it is rare for studies to focus specifically on engineering education or on an international perspective on the sector. Among the available resources, we have identified three quantitative and qualitative studies, and these have helped shape this report.

The first study focuses on China, India, and the United States and contains both quantitative and qualitative analysis of the production and utilization of engineers and technology specialists in the three countries. The study, "Getting the Numbers Right: International Engineering Education in the United States, China, and India," was conducted by Gary Gereffi, Vivek Wadhwa, Ben Rissing, and Ryan Ong (Gereffi et al. 2008). The study relies on a mixed methodology; it uses statistical analysis, interviews, and field research. For quantitative analysis, the study utilizes a cross-national data set on the number of engineering, computer science, and information technology degrees granted from 1994 to 2006, including bachelor's, master's, and doctoral degrees. The qualitative analysis was carried out through an examination of the educational policies of leading universities, interviews with executives and recruiters at multinational engineering firms, and assessments of the results of a 2005 survey by the McKinsey Global Institute, as well as other available literature (Farrell et al. 2005). The study concludes that the comparison is challenging because of variations in the definition of engineering from one country to another and, in some cases, inaccuracies and inconsistencies in the data. However, despite the challenges, the study found that the number of engineers in China and India is increasing more rapidly relative to the United States. In terms of the supply of engineers, through a top-down policy change adopted around 1990 in China and a bottom-up policy change in India, including a huge increase in the number of private institutions, both countries succeeded in raising university enrollments in engineering programs. On the demand side, in China, growth in the production of medium- and high-technology products, such as air conditioners and mobile telephones, in addition to traditional industries, including textiles, apparel, and footwear, has fueled the demand for engineers. In India, the demand for engineers has been augmented by the growth in the software and business process outsourcing industries. In both countries, multinational corporations have increased the number of research and development centers and the amount of foreign direct investment. An expansion in local firms in knowledge-intensive industries has also attracted high-quality engineers. Thus, the demand for engineers has risen, even though engineers are unemployed in both countries because of their lack of globally competitive qualifications. The study is based on a clear and detailed methodology in terms of data definition and data collection. It also provides a clear definition of the term engineer in each country and reflects significant effort in the identification of accurate data sources. We have tried to emulate these features in our study.

The second study is a qualitative analysis that provides a snapshot of current international comparative activities and experiences in the United Kingdom, an overview of the range of available resources to conduct comparative analysis, and proposals for future approaches to meet the needs of institutions of higher education in this area (PA Consulting Group 2011). The study was commissioned by the U.K. Higher Education Statistics Agency (HESA), conducted by PA Consulting Group, and published on October 20, 2011 under the title "International Benchmarking in U.K. Higher Education." The objective of the study was to extend the previous benchmarking report by HESA, which had focused on institutional operations, emphasizing the potential benefits of benchmarking for improving institutional efficiency and utilizing intranational data. Developing on the foundation of this previous study, the new study focuses on a review of international comparisons of the performance and the operations of international benchmarking to assess the potential for learning from other higher education systems. The methodology of the study is based on literature reviews and interviews among planning officers and other staff at U.K. universities that were chosen as samples. The findings show that international benchmarking is a relatively low priority among almost all the institutions that were the subject of the interviews. While most institutions collect and review comparative data on their international performance, few use them systematically in planning or management processes. Even if they use the data, they use them only in specific areas, mainly either detailed analyses of research performance or assessments of the perceptions of their international students. Some institutions use international institutional data as a tool to help identify potential research and teaching collaborators abroad. Others also use overseas market data and business intelligence resources to support decisions about a potential expansion into particular markets. Such examples of the use of benchmarking could be a reference for India. The research conducted for this second study was useful to us in identifying data sources and developing ideas for the eventual practical application of our international benchmarking study as a tool to improve engineering education in India.

Finally, EngineeringUK has conducted a quantitative and qualitative analysis on the engineering industry through a holistic approach and compiled a report, *EngineeringUK 2011: The State of Engineering* (Kumar and Randerson 2011). The report uses secondary data and analyzes both the demand side and the supply side of engineering, including government policy, employer perspectives, research and innovation, perceptions on engineering, employment outcomes, and engineering education, ranging from high school and higher education to vocational programs. While not international, the study provides key data for rigorously analyzing the situation of the engineering industry in the United Kingdom. In the area of research and innovation, the report provides information on the annual growth in the number of publications, in spending on research and development as a share of gross domestic product (which is comparable to the corresponding spending in other G-8 countries), and research and development expenditure by sector and country. For engineering education, data on gender- and subject-based school enrollments, the number of applicants, the number of graduates, employment following graduation, and salaries are available according to the level of educational attainment. For employability and skills, data on employer satisfaction and employment rates are provided. The analysis concludes that there is a growing demand for engineers, especially in the manufacturing sector, but that the supply of engineers is not sufficient. It also finds that the salaries of engineers are rather competitive; thus, more engineers should be produced in the future, especially if the issue of the lack of teachers is addressed. This report forms a basis for the section on the U.K. engineering education system of our study that is described in appendix A.

4. Scope of the Study

The countries included in our study are Brazil, China, India, Japan, Russia, the United Kingdom, and the United States. The focus of the study is the collection of basic, but important statistical information on engineering education in these countries. The original intention was to collect data on four areas, each of which is associated with multiple indicators: (1) students, faculty, and institutions (26 indicators); (2) education outputs (21 indicators); (3) education expenditures (3 indicators); and (4) research and commercialization outputs (14 indicators). In practice, we could not collect sufficient data to make meaningful comparisons on education expenditure. Most of the data available on this area refer only to higher education, but not specifically to engineering education. In addition, depending on the country, detailed breakdowns of the data are not available. Thus, our study compares only basic data on engineering education.

Differences in education systems, data availability, data definitions, and the timeliness of data collection also impose limitations on the ability of our study to provide a thorough comparison across the countries. In some cases, if data are not available, we have calculated estimates.

The study does not cover other important aspects of engineering education such as curricula, employability, pedagogy, learning outcomes and assessments, and so on. Building on this report, these important aspects might be a fruitful area of future research.

5. Survey Methodology

We have collected data through consultations with professors, researchers, and experts in different countries. Details on the indicators and the status of data collection on the indicators are listed in appendix D. In this study, we define engineering as mechanical, civil, electrical, and aerospace engineering and other types of engineering that are included within the engineering discipline as defined at each institution under examination. In some countries, computer engineering is included in the computer science discipline. The study thus covers all education disciplines in which the term engineering is included in the name of the discipline; thus, for example, the number of students and faculty in the computer engineering subdiscipline is also covered. The sources for the data on students, faculty, institutions, and education outputs are industry experts, ministry websites, and nonprofit statistics organizations focusing on higher education and engineering education. Data on research and commercialization outputs have been collected through Thomson Reuters and the Web of Science, including the Arts and Humanities Citation Index, the Science Citation Index Expanded, and the Social Sciences Citation Index databases.[8] The data definitions, data sources, and data years are described in appendix E.

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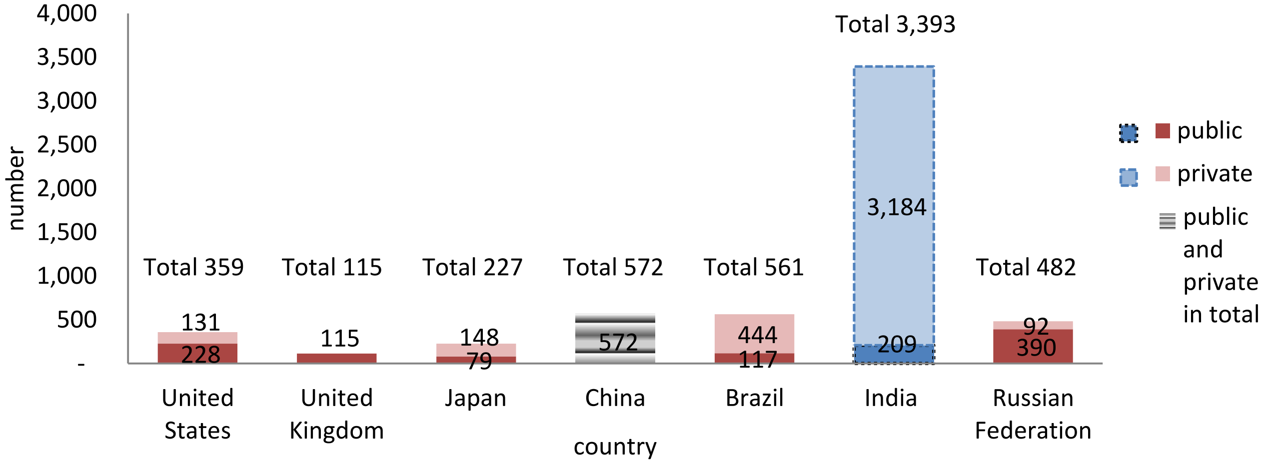
[8] Web of Science (database), Thomson Reuters, Philadelphia, http://thomsonreuters.com/products_services/science/science_products/a-z/web_of_science/.

6. Findings

Institutions

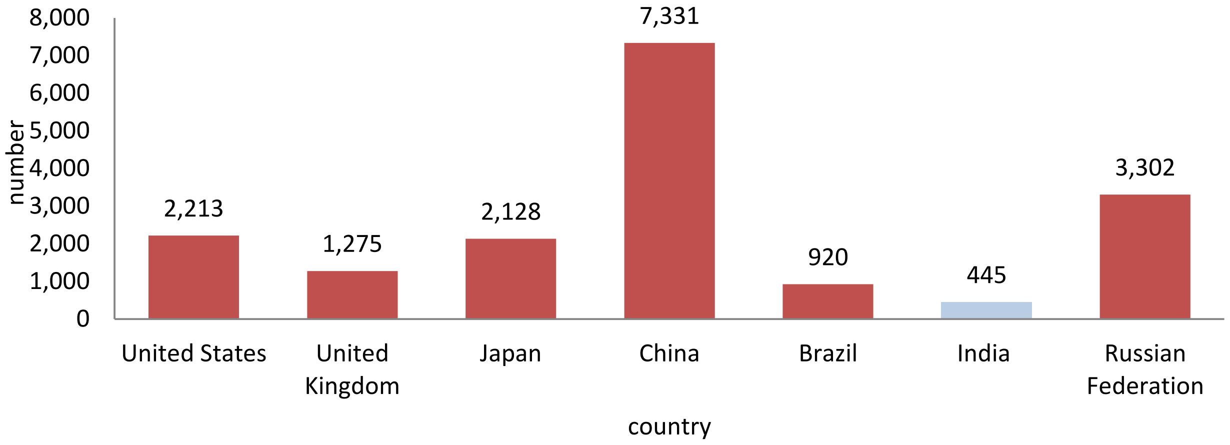
India has the greatest number of institutions relative to other countries (Figure 1). As discussed in section 2, the number of engineering institutions in India doubled between 2006 and 2011, from around 1,500 to 3,400; around half of these are unaided private institutions. However, India shows the lowest number of engineering students per institution among the countries in our comparison (Figure 2). The challenge facing small institutions is their limited financial resources whether from government funds or student fees. Thus, small institutions encounter difficulties in maintaining investments in the necessary upgrades in faculty skills and equipment, which are usually particularly expensive in engineering. It is also difficult for small institutions to form a critical mass of education professionals to provide support for other quality improvements.

Figure 1: Average Number of Institutions Providing Engineering Degrees



Sources: Various (see the data sources described in appendix E).
Note: The public-private distinction is not available for China.

Figure 2: Number of Engineering Students per Institution

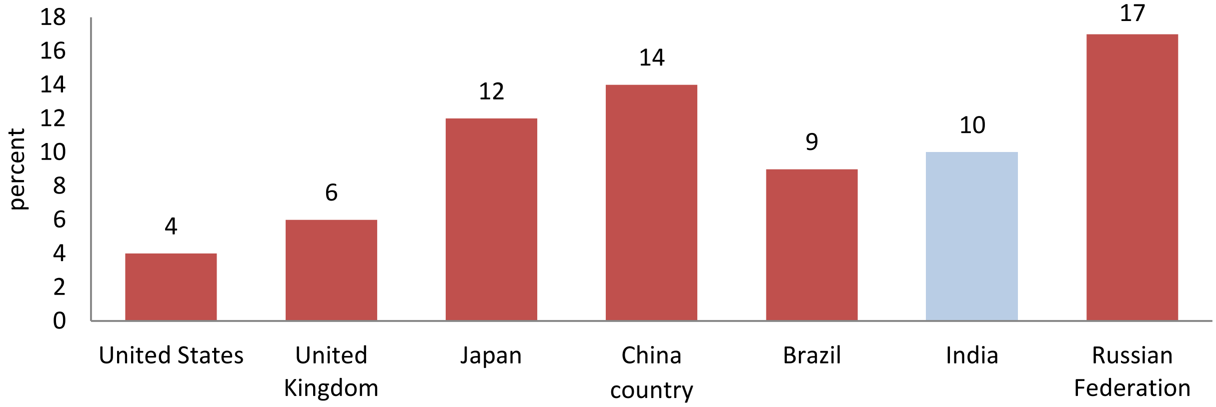


Sources: Various (see the data sources described in appendix E).

Students

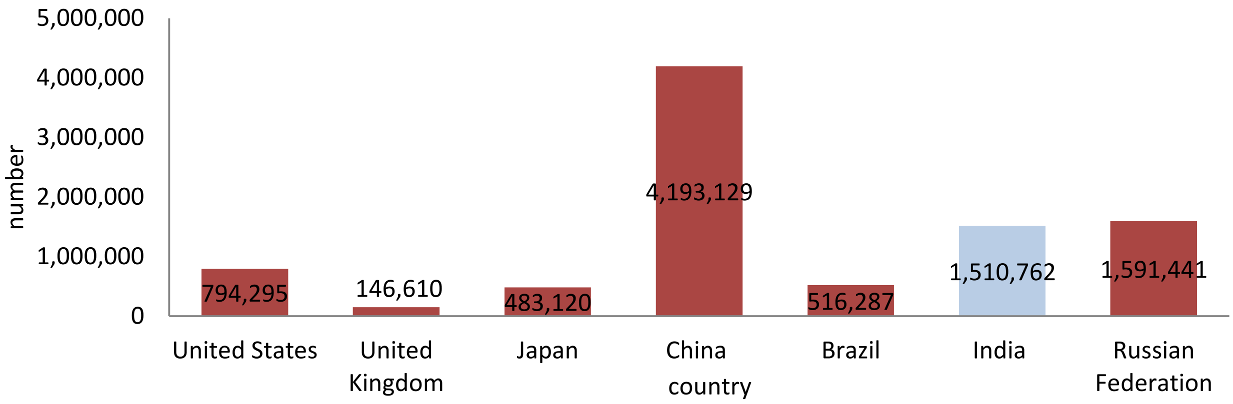
The share of engineering students among all students in higher education is around 10 percent in India, 14 percent in China, 12 percent in Japan, and 17 percent in Russia (Figure 3). The number of engineering students, including undergraduate and postgraduate students, is about 1,500,000 in India, which is less than the 4,200,000 in China, but about the same as Russia's 1,600,000 (Figure 4). However, relative to the total population of the country, the number of engineering students is actually the lowest in India (Figure 5). Indeed, the information technology sector, for instance, has reported shortages in qualified workforce (Ferrari and Dhingra 2009). The road sector, too, faces severe shortages in qualified workforce. The sector needs to increase hiring by at least two or three times the 2008 level of 6,000–7,000 engineers and diploma holders joining the sector workforce (World Bank 2008). Thus, India seems to need more engineering students.

Figure 3: Share of Engineering Students among All Students in Higher Education



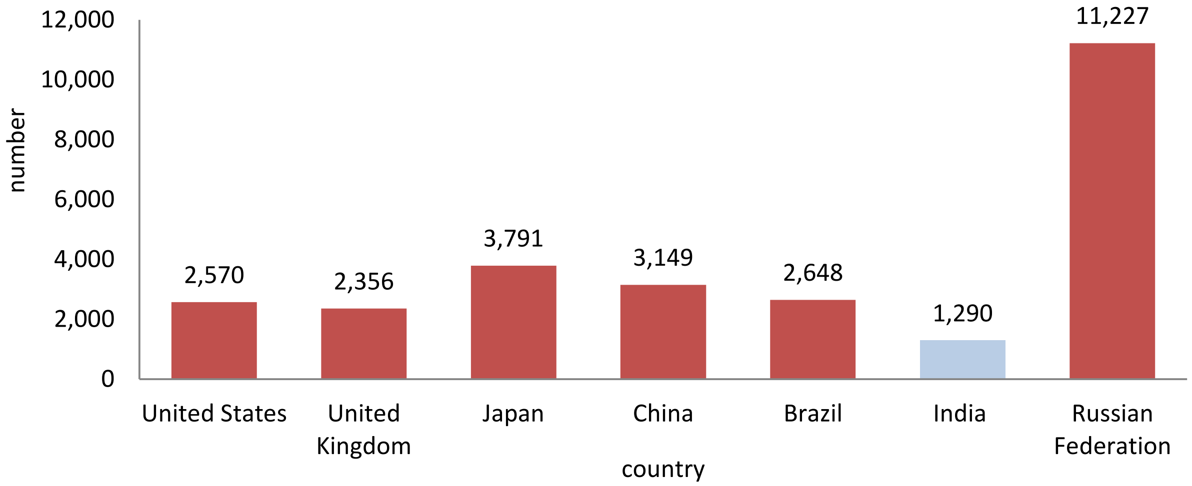
Sources: Various (see the data sources described in appendix E); India: data of 12th Five Year Plan; higher education enrollment data: Custom Tables (database), 2009, Data Center, Institute for Statistics, United Nations Educational, Scientific, and Cultural Organization, Paris, http://stats.uis.unesco.org/unesco/TableViewer/document.aspx?ReportId=136&IF_Language=eng&BR_Topic=0.
Note: Total enrollment in tertiary education includes public and private institutions and full- and part-time students. Students include undergraduate and postgraduate students.

Figure 4: Number of Engineering Students, Including Undergraduates and Postgraduates



Sources: Various (see the data sources described in appendix E).

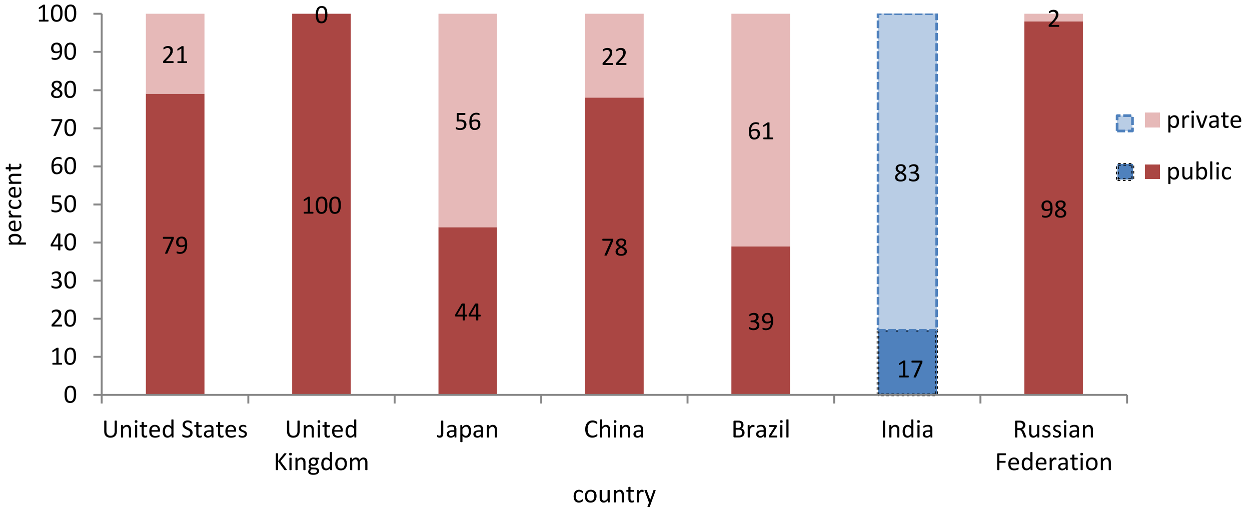
Figure 5: Number of Engineering Students, per Million Population



Sources: Various (see the data sources described in appendix E); population data: World Bank 2010.
Note: Students include undergraduate and postgraduate students.

In India, a significant proportion of students are enrolled in private engineering institutions (80 percent) relative to public institutions (Figure 6). The other countries examined in this study, except Brazil (61 percent) and Japan (56 percent), have more students in public institutions.

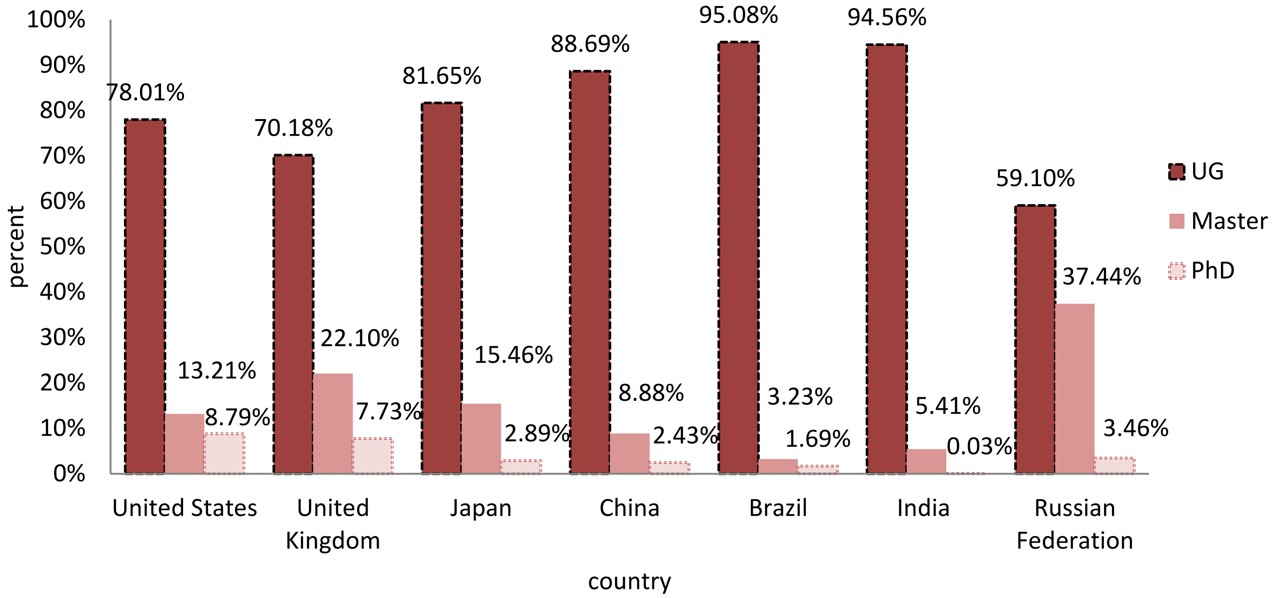
Figure 6: Share of Engineering Students in Public and Private Institutions



Sources: Various (see the data sources described in appendix E); data on Brazil, China, and India are estimates.
Note: Students include undergraduate and postgraduate students.

The proportion of students enrolled in PhD programs is less than 1 percent in India; this is the smallest share among the countries in our comparison (Figure 7). In addition, the proportion of students enrolled in master's programs is 5.4 percent, which is the smallest share except for Brazil. This is a major cause of the shortage in India of faculty with higher-level degrees (see below).

Figure 7: Share of Engineering Students, by Level of Education

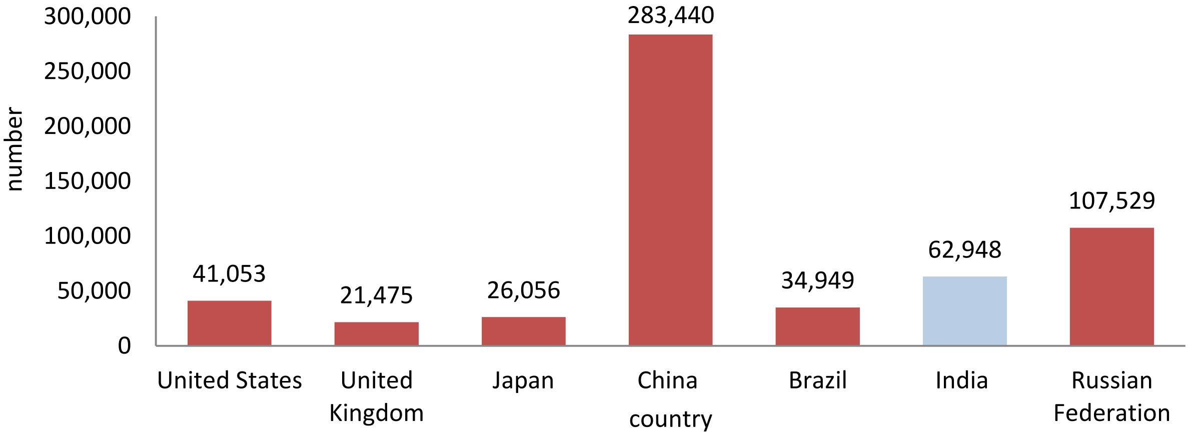


Sources: Various (see the data sources described in appendix E); data on India and Russia are estimates.
Note: Students include undergraduate and postgraduate students.

Faculty

Currently, there are no official data available on the number of engineering faculty in India. Based on the faculty-student ratio in general higher education, which is 1 to 24, one might estimate that there are 63,000 engineering faculty (MHRD 2011b) (Figure 8). Engineering faculty are more difficult to recruit than faculty in general higher education because potential faculty with higher degrees readily find employment in the corporate sector. It is therefore likely that the ratio of faculty to students is higher in engineering than in higher education as a whole, and, so, the number of faculty is likely to be less than the 63,000 estimate above.

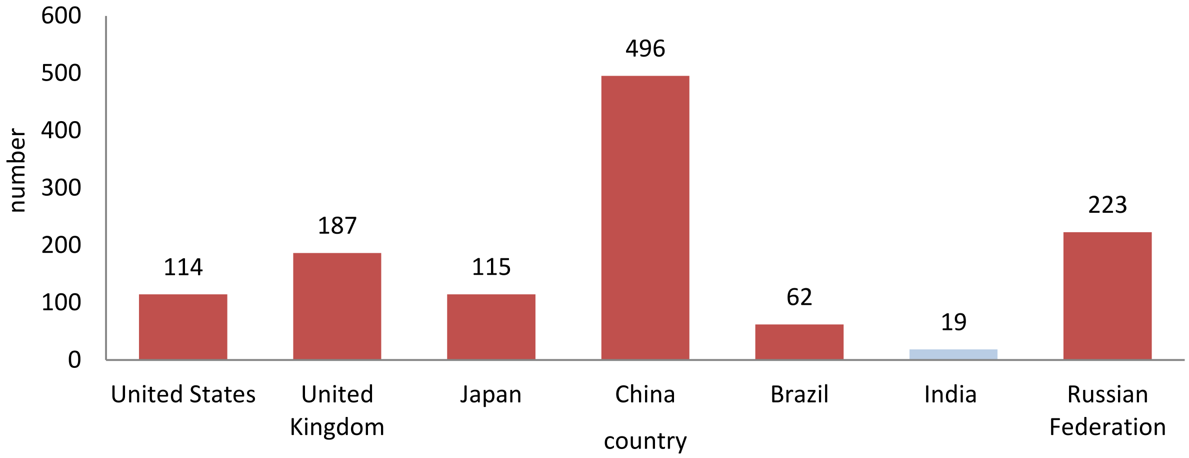
Figure 8: Number of Engineering Faculty



Sources: Various (see the data sources described in appendix E).

The faculty shortage has been a topic of discussion within the engineering education system in India for a long time. The number of engineering faculty seems comparable among the countries examined in this study. The issue in India seems to be the exceptionally large number of engineering institutions, which leads to the low numbers of students and faculty per institution. Assuming that the number of faculty is close to the true situation, the number of engineering faculty per institution is quite low, at 19 (Figure 9).

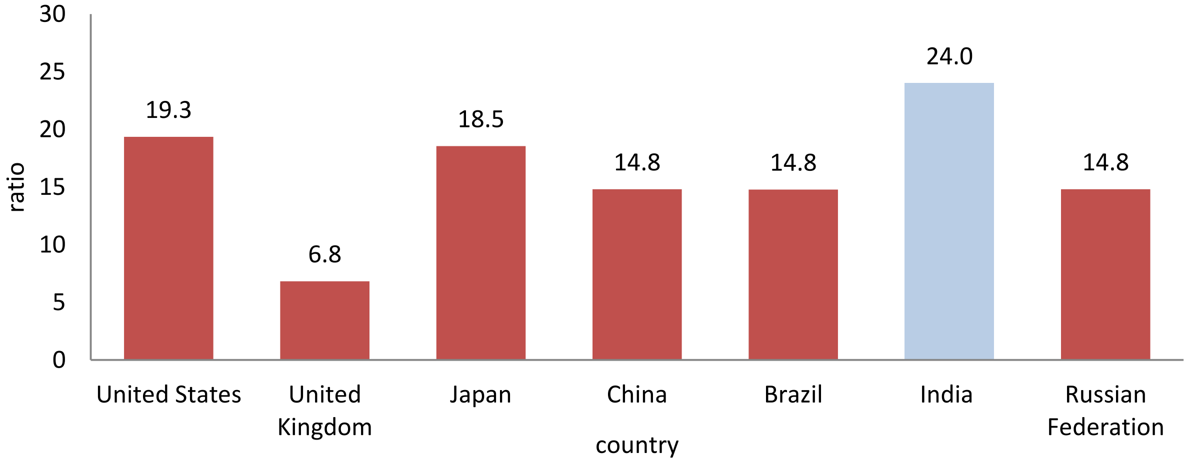
Figure 9: Number of Engineering Faculty per Institution



Sources: Various (see the data sources described in appendix E).

Even a conservative estimate of the ratio of students to faculty in engineering education in India is the highest such ratio among the countries in our comparison (Figure 10). Given that the AICTE norm suggests that the faculty-student ratios at the undergraduate and postgraduate levels are 1 to 15 and 1 to 12, respectively, the ratio of 1 to 24 is significant and indicates that the shortage of engineering faculty is severe if indeed the estimate of the number of engineering faculty is correct.

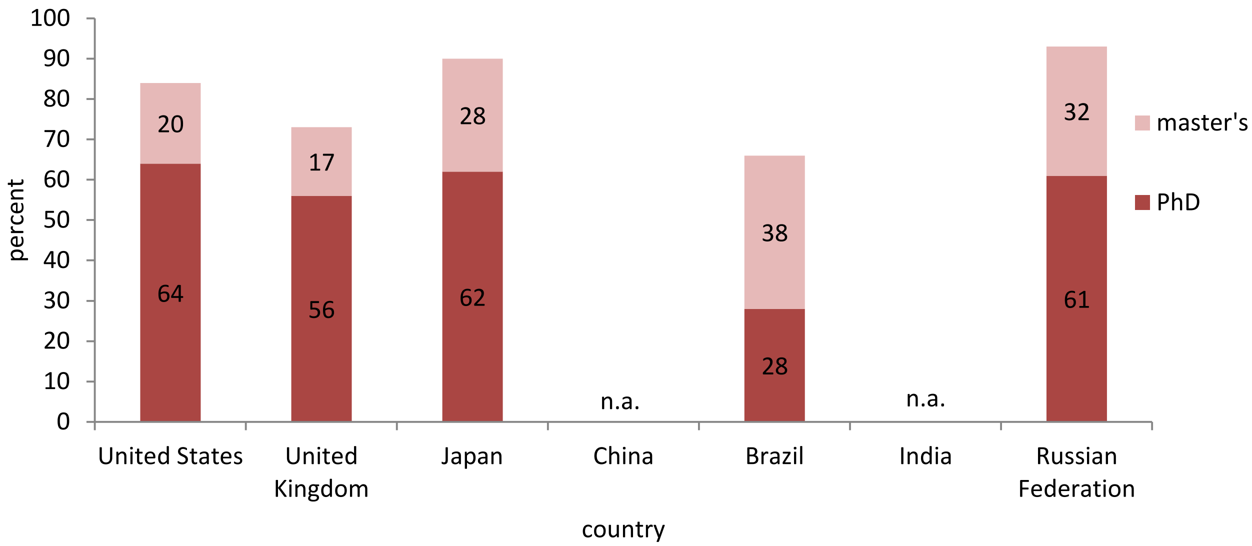
Figure 10: Student-Faculty Ratio in Engineering Education



Sources: Various (see the data sources described in appendix E).

The issue of the engineering faculty in India is not only one of quantity; it is also an issue of quality. The percentage of engineering faculty with PhD degrees is low. Even at competitively selected institutions involved in the TEQIP-II in Andhra Pradesh, one of the most advanced states in terms of engineering education, the share of engineering faculty with PhD degrees is merely 20 percent. This is low even among the BRIC countries (Figure 11).

Figure 11: Average Qualifications of Faculty

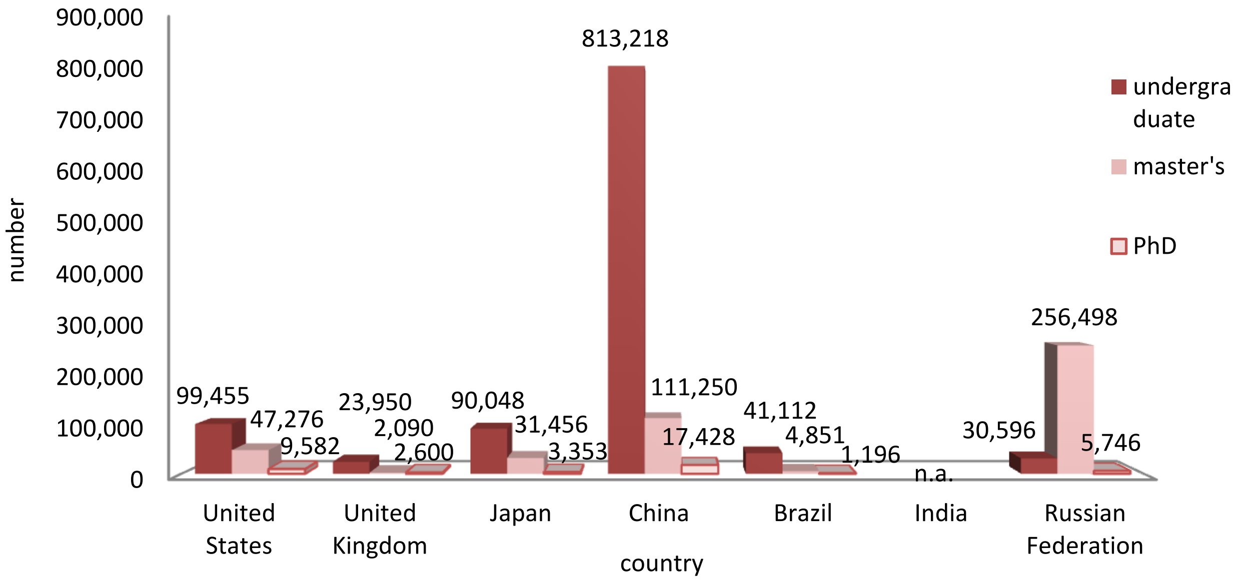


Sources: Various (see the data sources described in appendix E); Brazil: data of National Institute for Educational Studies and Research; data on Russia are estimates; United States: data of National Center for Education Statistics.
Note: Faculty includes only members with master's degrees or PhDs.

Education Outputs

The latest available data on education outputs in India refer to 2006. According to Banerjee and Muley (2009), India awarded about 230,000 engineering degrees, 20,000 engineering master's degrees, and about 1,000 engineering PhDs in 2006. These may be reference figures for comparison. However, given that engineering education in India has significantly expanded and that there are no recent data available on engineering graduates, we have omitted the number of graduates in India (Figure 12). Among the countries that we compare, China is producing the highest number of engineering graduates by far.

Figure 12: Number of Graduates, by Level of Education



Sources: Various (see the data sources described in appendix E); the data on Russia are estimates; United States: Yoder 2012, NCSES 2012.
Note: The data on the United States represent the sum of engineering graduates and engineering technology graduates.

Research and Commercialization Outputs in Institutions

The quality of research activities is one of the most important aspects in assessing the quality of engineering education institutions, especially research universities. Yet, research outcomes are not necessarily an appropriate indicator in terms of fully defining and measuring the quality of institutions, considering that there are universities and colleges focusing on teaching or on improving access to higher education. Nonetheless, the number of publications, reference citations, and patents may indicate, at least to some extent, the quality of the knowledge production at institutions. These three indicators—the number of publications, reference citations, and patents—are often used in bibliometric studies that quantitatively evaluate research capacity and quality at the level of both individuals and institutions. An examination of these indicators may be worthwhile given the desire in India to produce more highly skilled engineers. Such information would also be useful for decision making on future research funding.

First, we examine the changes in the volume of publishing, reference citations, and patents in the engineering field between 2000 and 2010.[9] Our report presents the changes over the past decade in (1) the capacity of research as measured by the number (volume) of publications, (2) the quality of research as measured by the number (volume) of reference citations, and (3) the ability to commercialize research as measured by the number (volume) of patents. While it is important

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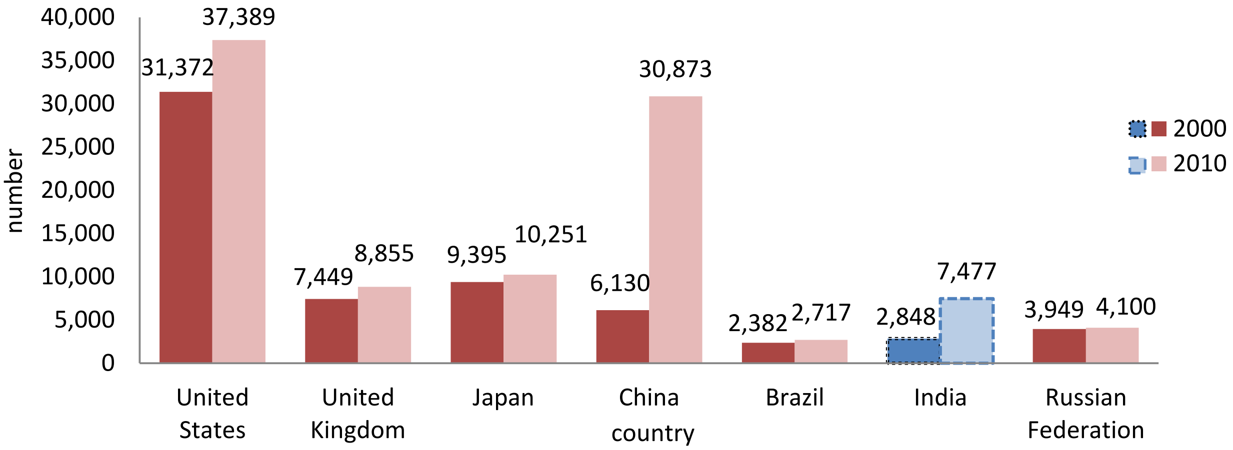
[9] These two data years have been chosen because the AICTE and the MHRD wished to consider the changes generated by the TEQIP-I in the engineering education system in India. The first phase of the TEQIP-I was launched in 2002 and was successfully completed in 2009. A 2010 report offers a detailed analysis with more data points from 2000 to 2010, indicating an upward trend in research outcomes (IISc 2010).

to show absolute numbers, the outcomes according to the volume of research are naturally more significant in terms of impact in a larger engineering education system. Therefore, we also look at the number of publications, citations, and patents per faculty member. This helps show the capacity of faculty members in terms of research activities.

Publications (volume)

The number of publications is often used to measure research volume. In our study, the publications surveyed include standard primary (peer-reviewed) research articles in English on engineering, but not conference proceedings, editorials, or letters.[10] Figure 13 shows the number of engineering publications in English in respective countries in 2000 and 2010. While the number of engineering publications in the BRICs did not exceed that in Japan, the United Kingdom, and the United States in 2000, the picture changed in 2010 because of a significant increase in publishing in China and India. The increase in China was more than fivefold. Publishing in India rose by more than twofold: the country extended the gap with Brazil, overtook Russia, and is approaching the absolute level of the United Kingdom.

Figure 13: Number of Publications on Engineering, 2000 and 2010



Source: Web of Science (database), Thomson Reuters, Philadelphia, http://thomsonreuters.com/products_services/science/science_products/a-z/web_of_science/, including the Arts and Humanities Citation Index, Science Citation Index Expanded, and Social Sciences Citation Index databases.

Citations (volume)

India is also now comparable with Japan and the United Kingdom in terms of the number of reference citations, though it is still considerably behind the United States and, now, also China. The number of citations is often used as a proxy to measure research quality. The number of

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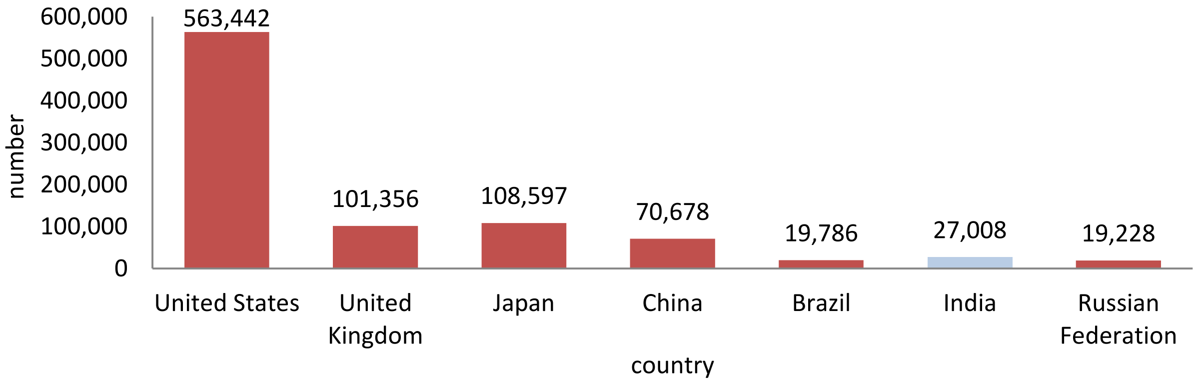
[10] The term engineering in this case includes agricultural engineering, automation control systems, cell tissue engineering, engineering aerospace, engineering biomedical, engineering chemical, engineering civil, engineering electrical electronic, engineering environmental, engineering geological, engineering industrial, engineering manufacturing, engineering marine, engineering mechanical, engineering multidisciplinary, engineering ocean, engineering petroleum, mechanics, metallurgical engineering, metallurgy, and robotics.

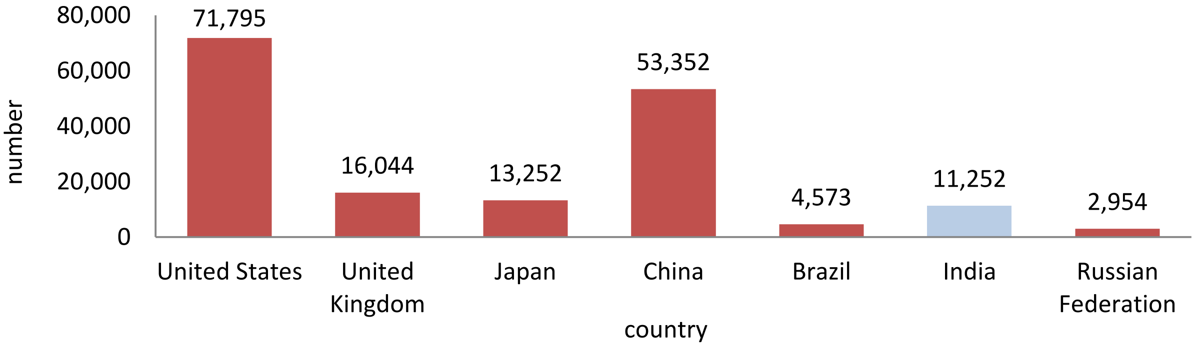
citations is defined as the sum of the times a work is cited, less any self-citations. The term engineering is used in the same way as in the case of publishing. Figure 14 shows the number of citations of research articles published in 2000 and 2010 as of February 2012. For instance, the number of citations of research articles published in 2000 in India was around 27,000 as of February 2012. Similarly, the number of citations of research articles published in 2010 in India was about 11,250 as of February 2012. Naturally, the former is larger because the count covers 10 years, while the latter covers only 2 years. Figure 14compares not the absolute number, but the overall shift in the pattern in the volumes between 2000 and 2010. In 2000, none of the BRICs exceeded the number of citations associated with Japan, the United Kingdom, and the United States. However, in 2010, China was second in the volume of citations. India is now comparable with Japan and the United Kingdom in terms of this volume.

Figure 14: Cumulative Number of Citations of Articles on Engineering, 2000 and 2010

a. 2000



b. 2010



Source: Web of Science (database), Thomson Reuters, Philadelphia, http://thomsonreuters.com/products_services/science/science_products/a-z/web_of_science/, including the Arts and Humanities Citation Index, Science Citation Index Expanded, and Social Sciences Citation Index databases.

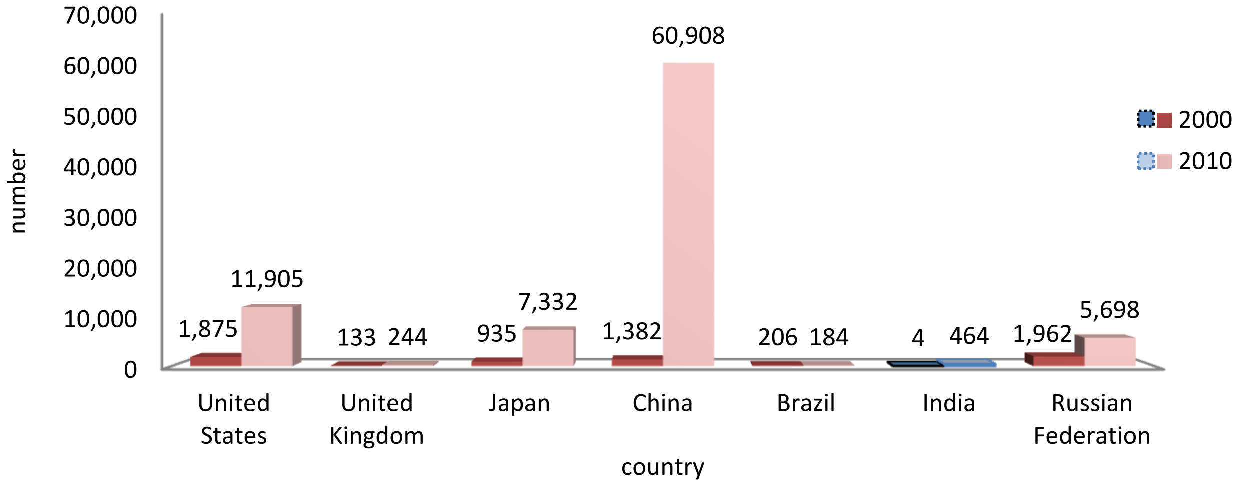
Patents granted to engineering institutions (volume)

The number (volume) of patents indicates, to some extent, the capacity of applied research, which is crucial for the success of developing countries such as India. We have compared trends in patenting using data from the Thomson Reuters value added patent collection, the Derwent World Patents Index (DWPI).[11] There are several attributes that may be measured to identify and track innovation trends in a particular region (Zhou and Stembridge 2008):

- The *total volume of patents* gives a measure of the total patenting activity in a region. It involves two aspects: inventions that are patented first in a country (the DWPI basics) and other inventions for which protection is sought to manufacture, use, or sell the inventions or products in the country (the DWPI equivalents).[12]
- The *volume of basic patents* gives a clearer measure of homegrown innovation by providing data on the number of inventions patented first in respective countries.

India substantially increased its total volume of patents between 2000 and 2010; its total volume surpassed that of Brazil and the United Kingdom in 2010. The patents highlighted in Figure 15 are those granted to engineering institutions only, not to corporations. The figure shows the total number of patents granted to engineering schools globally in a particular country. For example, the total number of patents granted to all engineering schools globally in the United States in 2000 was 1,875. China, too, exponentially increased its total volume of patents between 2000 and 2010. It dominated in the number of patents generated at engineering institutions in 2010.

Figure 15: Total Volume of Patents at Engineering Institutions



Source: Derwent World Patents Index (database), Thomson Reuters, Philadelphia, http://thomsonreuters.com/products_services/legal/legal_products/a-z/derwent_world_patents_index/.
Note: For information on the number of engineering institutions, see the data sources described in appendix E.

The overall picture for homegrown patents is similar: China is far ahead of all other countries. Figure 16 shows the patents granted first to engineering institutions in the respective countries.

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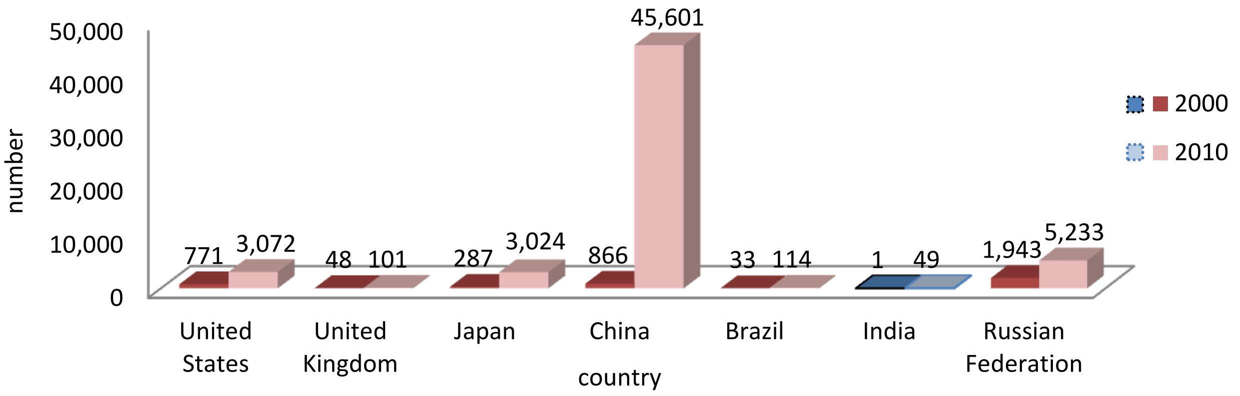
[11] Derwent World Patents Index (database), Thomson Reuters, Philadelphia, http://thomsonreuters.com/products_services/legal/legal_products/a-z/derwent_world_patents_index/.

[12] The total volume of patents, the volume of basic patents, and the share of basic patents in the total volume of patents are defined by Thomson Reuters.

These are the homegrown patents granted to such institutions. The overall picture is similar to that in Figure 15. The number of basic (homegrown) patents granted to engineering institutions in India is remarkably low compared with the numbers in all other countries in both 2000 and 2010. This indicates that the capacity to develop inventions at engineering institutions in India is not as competitive. As in the case of the total volume of patents, engineering institutions in China are exhibiting vigorous growth in the volume of basic patents.[13]

Figure 16: The Volume of Inventions (Basic Patents) at Engineering Institutions



Source: Derwent World Patents Index (database), Thomson Reuters, New York, http://thomsonreuters.com/products_services/legal/legal_products/a-z/derwent_world_patents_index/.
Note: For data on the number of engineering institutions, see the data sources described in appendix E.

Examining the quality of the patents granted in the respective countries, in addition to the quantity, is beyond the scope of this study. However, one should be cautious in interpreting the data on the volume of patents, especially in China, which shows exceptional growth in both the total volume of patents and the volume of basic patents. One of the reasons for the significant increase in both indicators in China from 2000 to 2010 is, as Zhou and Stembridge (2008) point out, that the Chinese government encourages industries to protect their intellectual property through laws by providing them with subsidies to cover patent application costs. Furthermore, most patents filed in China are for minor design changes or new models, which do not require great technical innovation.

The capacity of individual faculty in research activities

The average annual number of publications per 100 faculty members in China and India are almost the same, at eight and nine, respectively. The number of articles in English on engineering and the reference citations to such articles have increased in China and India. However, if the numbers are divided by the number of faculty, Japan, the United Kingdom, and the United States maintain their advantage over the BRICs (Figure 17). For instance, every 100 faculty members in engineering education in the United States publish an average of 64 papers per year. In Japan and the United Kingdom, an average of 28 papers are published per 100 engineering faculty each year. Faculty members in the BRIC countries seem to struggle to produce papers compared with faculty in Japan, the United Kingdom, and the United States. The

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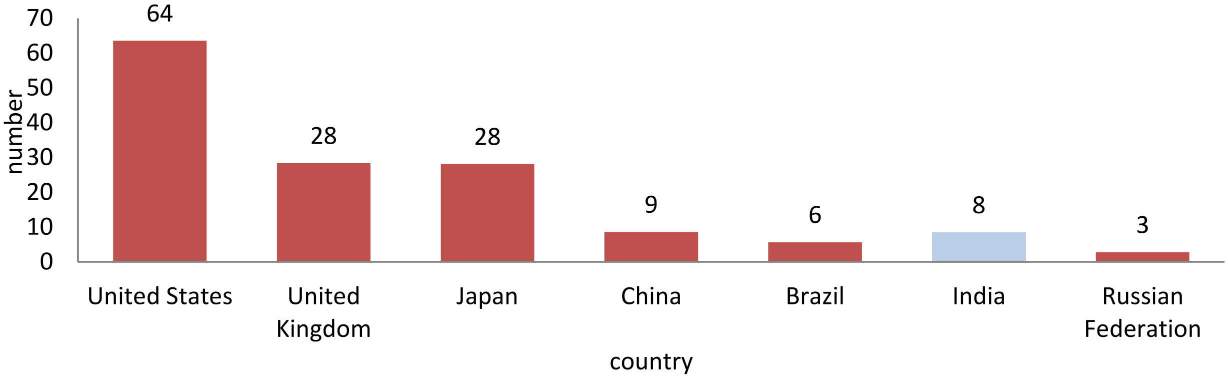
[13] Zhou and Stembridge (2008) offer a detailed analysis of patents and trends in patents at the country level.

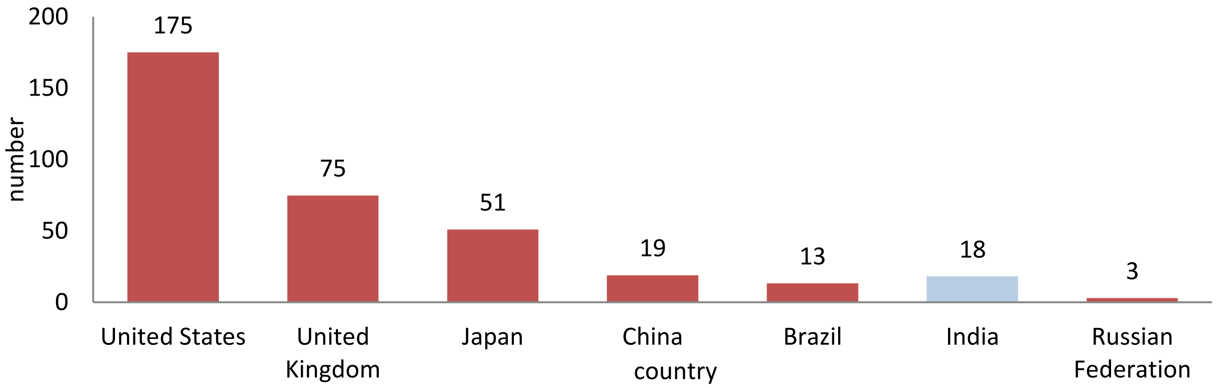
number in India is only slightly higher than the number in Brazil and Russia, but considerably lower than the number in Japan, the United Kingdom, and the United States. A similar pattern is evident in the number of citations per 100 faculty members (Figure 18). Engineering papers published by Indian faculty are cited rather rarely. The numbers are comparable across the BRIC countries, but significantly higher in Japan, the United Kingdom, and the United States. The volume of basic patents per 100 faculty members is even more unfavorable for the BRICs (except China), and India shows the lowest volume among all the countries (Figure 19). The low volume of basic (homegrown) patents is especially worrisome because this indicates the weak capacity of engineering faculty (and institutions) to respond to needs in the domestic market. It also reflects the want of strong university-industry partnerships. For a country such as India, it is important to improve the capacity of applied research in collaboration with industry.

Figure 17: Number of Articles on Engineering per 100 Faculty Members, 2011



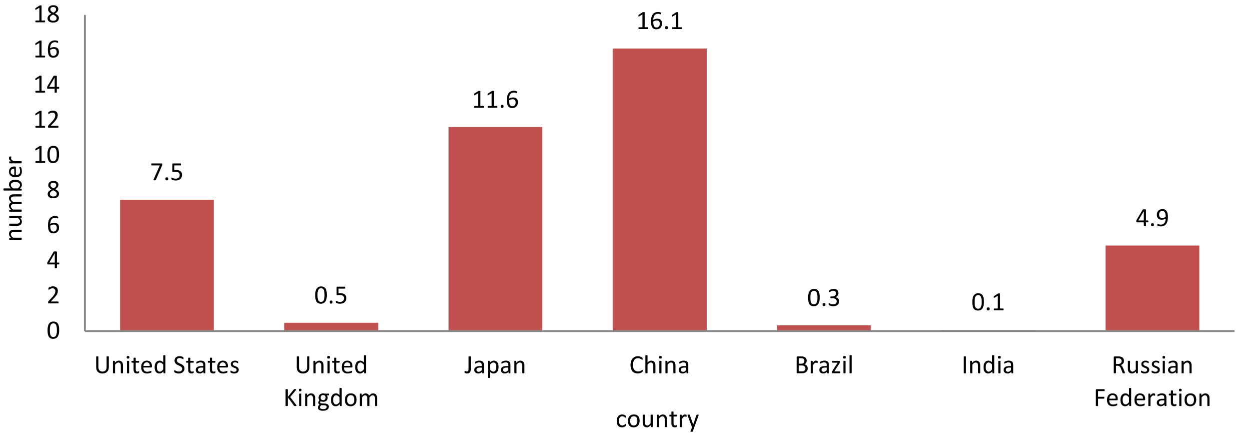
Source: Web of Science (database), Thomson Reuters, Philadelphia, http://thomsonreuters.com/products_services/science/science_products/a-z/web_of_science/, including the Arts and Humanities Citation Index, Science Citation Index Expanded, and Social Sciences Citation Index databases.
Note: For data on the number of faculty, see the data sources described in appendix E.

Figure 18: Number of Citations to Articles on Engineering per 100 Faculty Members, 2010



Source: Web of Science (database), Thomson Reuters, Philadelphia, http://thomsonreuters.com/products_services/science/science_products/a-z/web_of_science/, including the Arts and Humanities Citation Index, Science Citation Index Expanded, and Social Sciences Citation Index databases.
Note: For data on the number of faculty, see the data sources described in appendix E.

Figure 19: Volume of Inventions (Basic Patents) at Engineering Schools per 100 Faculty, 2010



Source: Web of Science (database), Thomson Reuters, Philadelphia, http://thomsonreuters.com/products_services/science/science_products/a-z/web_of_science/, including the Arts and Humanities Citation Index, Science Citation Index Expanded, and Social Sciences Citation Index databases.

Note: For data on the number of engineering institutions and faculty, see the data sources described in appendix E.

7. Conclusion

We have conducted the analyses with the best available data. It has revealed several important facts. This section summarizes these findings of our study and suggests areas for further research. It should be recalled that the objective of this study is not to provide specific policy recommendations. Instead, it should serve as a foundation to promote discussion among policy makers and stakeholders in India.

First, *there is a large number of engineering institutions in India.* The exponential expansion in the engineering education system has arisen mainly because of an increase in the number of private institutions. Now, 90 percent of the engineering institutions in India are privately managed. This increase may have helped improve the access to engineering education. However, one result has been a low number of student and faculty per institution. The current estimated faculty-student ratio of 1 to 24 should be improved to approach the AICTE norm (1 to 15 among undergraduates and 1 to 12 among postgraduates). Appropriate regulations on private institutions in this area would help the entire Indian engineering education system improve quality and efficiency. In this regard, the future of the affiliation system might be discussed. For instance, clustering colleges might be a potential practical policy option in reforming the affiliation system, and it might improve the deployment of the limited number of faculty (Sanyal 2012). Clustered colleges could share financial, human, and physical resources. They could eventually be upgraded to universities under certain conditions. A point of discussion might be the status and future of the large number of small private engineering institutions (see above).

Second, *access to engineering education remains an issue.* The number of students is not sufficiently large relative to the size of the population. There are approximately 1,510,000 students enrolled in engineering schools, including undergraduates and postgraduates, which is quite high, though the number is less than the number in China (4,193,000) and Russia (1,591,000). However, relative to the size of the population, the proportion of engineering students is lowest in India (1,290 students per million population). Indeed, the demand for quality engineers is quite significant in infrastructure development and in industry, especially the information technology industry. Thus, there is still room to encourage an increase in the number of engineering students by fostering better access to engineering education and by making engineering education more attractive to students. Enhancing the quality of education and the availability of student financing could thus be important steps.

Third, *there is a substantial shortage of qualified faculty*. The percentage of faculty with PhDs is low in India. Even in top institutions in an advanced state such as Andhra Pradesh, only 20 percent of faculty members hold PhDs. This is so because few engineering students are pursuing PhDs. Only 1 percent of all engineering students are enrolled in PhD programs. If India aims to become more competitive in research outcomes, the number of PhD students and faculty with PhDs needs to be raised. Given that the majority of faculty members have only a master's degree, providing them an opportunity to upgrade their degrees to PhDs might be a realistic option for improvement over the short to medium term while the government tries to increase the number of PhD students coming out of the system.

Fourth, *only limited data are available on the engineering education system.* A mechanism is required as quickly as possible to collect, monitor, and evaluate engineering education data regularly. The most challenging task we faced in carrying out this study was the collection of recent accurate data in India. For instance, the most recent data available on the number of graduates are from 2006. Furthermore, basic information such as the number of students, faculty, and institutions often varies depending on the official sources. A robust data system is indispensable for any deeper analyses of higher education and the engineering education system.

Finally, *the quality and number of research activities have increased in India, but there is room for more improvement*. Research and commercialization outputs have been enhanced. Between 2000 and 2010, the number of publications on engineering matters rose by more than twofold, approaching the number in the United Kingdom (7,500 and 8,900 in 2010, respectively). The number of reference citations of publications, a proxy for research quality, also became more comparable in India relative to Japan and the United Kingdom (11,200, 13,200, and 16,000, respectively). The volume of all patents and the volume of basic patents also steadily rose in India from 2000 to 2010. However, compared with other countries, the number of patents remains low. In particular, the low volume of basic patents indicates the weak capacity of engineering institutions to respond to needs in the market. In addition, the capacity of individual faculty to carry out research activities is not as good as it should be, especially in terms of patents. Leaders at educational institutional should consider expanding their collaboration with industry.

Appendix A. System and Trends in Engineering Education

The United States

Brian Yoder, American Society for Engineering Education

Overview

The number of earned engineering and engineering technology degrees at all levels has increased over the past decade in the United States, with the exception of engineering technology degrees at the associate level (Table 2). From 2002 to 2011, the number of earned doctorates in engineering rose by 40 percent; master's degrees, by close to 35 percent; and bachelor's degrees, by 20 percent (Yoder 2012). The number of earned bachelor's degrees in engineering technology increased by 5 percent.

Table 2: Earned Engineering and Technology Degrees, United States, 2002–11

Total

Degree	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*
Earned engineering degrees, 2002–11										
Doctoral degrees	5,772	5,870	6,604	7,333	8,351	9,055	9,086	9,083	8,995	9,582
Master's degrees	31,089	35,196	39,837	40,550	39,015	36,983	38,986	41,632	43,023	46,940
Bachelor's degrees	66,781	71,165	72,893	73,602	74,186	73,315	74,170	74,387	78,347	83,001
Earned engineering technology degrees, 2002–09										
Bachelor's degrees	15,637	15,591	15,341	15,649	15,327	15,894	16,164	16,454	n.a.	n.a.

Sources: Yoder 2012; NSB 2012.
Note: n.a. = not applicable.

While the overall growth in the number of engineering degrees awarded is impressive, it has not kept pace with the growth in the number of all degrees awarded in the United States, and the proportion of engineering degrees to all degrees awarded is less now than it was 10 years ago.[1] In part, this trend can be attributed to changes in the U.S. economy. U.S. manufacturing, which hires many engineers, has declined over the past couple of decades, while the service sector, which does not hire as many engineers, has increased; thus, not as many engineers are needed as a proportion of the overall economy as in the past. Yet, a recent ManpowerGroup (2012) global survey indicates that employers are having a hard time finding qualified engineers. In the United States, one of the top reasons for not finding qualified engineers is the fact that job candidates lack the required hard skills.

There is a difference between engineering and engineering technology degrees. Engineering students take more mathematics courses and study a higher level of mathematics relative to

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[1] See "Fast Facts: Degrees Conferred by Sex and Race" and "Related Tables and Figures," National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education, Washington, DC, http://nces.ed.gov/fastfacts/display.asp?id=72. A comparison of data on 2009 with data on the situation 10 years earlier reveals that the number of engineering and engineering technology degrees awarded as a share of the overall number of degrees awarded fell from 6 to 5 percent. See "Table 282: Bachelor's Degrees Conferred by Degree-Granting Institutions, by Field of Study, Selected Years, 1970–71 through 2008–09," *Digest of Education Statistics, 2010*, National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education, Washington, DC, http://nces.ed.gov/programs/digest/d10/tables/dt10_282.asp?referrer=list.

engineering technology students. Engineering programs focus on theory. After graduation, engineering graduates are called engineers and spend their time planning rather than implementing. Engineering degrees most often terminate at the bachelor's degree, considered the professional degree in the field, or, the degree level required that allows students to become a licensed engineer, but students may continue their studies to graduate with a master's degree or a PhD in engineering. Engineering technology students take fewer mathematics courses and study a lower level of mathematics relative to engineering students. Engineering technology programs focus on applications. Graduates of engineering technology programs are called technologists and spend their time implementing plans developed by engineers. Engineering technology degrees mostly terminate at the associate's degree, the bachelor's degree, and, in some cases, the master's degree.

Engineering and engineering technology degrees are granted by engineering schools found within both public and private colleges and universities. A college is a stand-alone institution of higher education and typically has several departments. A university is an institution of higher education that houses several colleges. There are currently about 380 accredited engineering schools and about 130 engineering technology schools in the United States, public and private. Both public and private schools of engineering and engineering technology produce quality graduates, but private schools are able to select students who are more well prepared. This means that some engineering schools at public colleges and universities have a mandate to accept any student who enrolls in their programs and therefore may have fewer well-prepared students in their programs relative to private schools.

A relatively new category of engineering school in the United States is the for-profit school. These schools have shareholders who invest money in the schools in return for a dividend. Often, courses are taught online.

There are over 100 for-profit schools in the United States. Not all of them offer engineering degrees. Two of the largest schools, DeVry University and University of Phoenix, offer engineering degrees. Compared with public and private schools, for-profit schools educate a disproportionate number of disadvantaged, minority, and older students (Deming, Goldin, and Katz 2011). Students sometimes choose for-profit schools because the students lack other opportunities to pursue tertiary education; other students attend because they appreciate the flexibility afforded by the online courses of for-profit schools. For-profit schools tend to have lower admissions criteria relative to public and private schools.

Schools of engineering and engineering technology, whether part of a public or a private university or college, receive funding from many of the same sources, although the proportion of funding from the different sources varies. Both public and private schools receive subsidies from federal, state, and local governments. Public schools generally receive a larger percentage of their funds from governments relative to private schools.

Both public and private engineering and engineering technology schools charge tuition fees paid by students. The fees vary among schools. Fees at private schools tend to be higher than those at public schools. Some universities and colleges have differential tuition, meaning that the engineering schools charge their students tuitions that are higher than the tuitions charged to students in other schools because the delivery of engineering education is more expensive than the delivery of education in other schools.

Differential tuition is decided by the university or college administration at both public and private schools in accordance with the university or college governance processes and procedures. Differential tuition may run from a few hundred dollars to a few thousand dollars a semester and is used to hire more faculty, equip labs, and improve the quality of the instruction the engineering students receive.

Centers, departments, and faculty at schools of engineering also receive competitive and noncompetitive grants to conduct research in a variety of areas related to engineering. Funds may come from federal agencies, state and local governments, foreign governments, and industry. Research funds can be used to pay for research equipment, faculty and staff salaries, and student stipends.

Quality assurance

Established in 1932, the Accreditation Board for Engineering and Technology (ABET) is the recognized U.S. accreditor of college and university engineering programs. ABET is a nongovernmental organization and consists of a federation of 31 professional and technical member societies representing the fields of applied science, computing, engineering, and technology. Member societies include the American Society of Civil Engineers, the American Society for Engineering Education (ASEE), and the Society of Manufacturing Engineers. ABET specifies minimum curricula for various engineering programs. For instance, for the bachelor's degrees in engineering, ABET requires students to complete at least one year of mathematics and natural science, as well as a capstone project or design class. Because of ABET's involvement, engineering curricula are somewhat standardized across engineering schools at the bachelor's degree level.

Accreditation is voluntary and is given to individual programs within an institution rather than to the institution as a whole. The accreditation process can take up to 18 months. Accredited programs must be reevaluated every six years to retain accreditation. Programs without previous accreditation can apply for accreditation as long as they have produced at least one graduate.

ABET accreditation is initiated by the institution seeking accreditation. As a first step, the institution must request an evaluation. The program within the institution under accreditation then conducts an internal evaluation and completes a self-study report. The self-study is based on established accreditation criteria and shows how well the program is performing in key areas.

ABET then chooses an evaluation team consisting of a team chair and program evaluators. The evaluation team members are volunteers and come from government, industry, academia, and private practice.

The evaluation team visits the campus of the institution. This visit normally lasts three to four days. The program's self-study report forms the basis of the evaluation. During the visit, the evaluation team will interview students, faulty, and administrators, as well as review course materials and student sample assignments and sample projects. The visit will conclude with an exit interview of the institution’s chief executive officer, dean, and other institution personnel as appropriate.

After the visit, the program has opportunities to correct any factual errors in the report and address any issues identified in the report. The final statement and recommended accreditation action are reviewed at a large annual meeting of all ABET commission members in July. Based on the findings, the commission members vote on the final accreditation action, and the school is notified of the decision in August.

Currently, about 380 engineering schools and about 130 engineering technology schools in the United States, both public and private, are accredited by ABET. Not all engineering and engineering technology schools in the United States have ABET accreditation, but most do. New schools must graduate their first student before they can request an evaluation from ABET; so, new schools will go unaccredited until after the graduation of the first student. Other schools, for whatever reason, have never applied for ABET accreditation, but there are not many. Also, it is possible for a school to lose its accreditation and then regain it. For students who want to study engineering in graduate school or apply for professional engineering certification, it is important that they study at an ABET-accredited school.

Schools must adhere to any federal and state higher education regulations and laws that affect colleges and universities in general. Engineering schools are not highly regulated by federal and state governments directly; for example, there are no laws that specify required courses, but schools are affected by licensure regulations and accreditation.

While not a direct regulation on schools, licensure requirements for individual engineers affect engineering school curricula. For instance, individual states manage the licensure of professional engineers, and a frequent licensure requirement is that the licensee must have graduated from an ABET-accredited four-year university program in engineering. Thus, for schools to attract students, they must have ABET accreditation so their students can become licensed engineers. State licensure requirements are not a direct state or federal regulation on engineering schools, but they affect school curricula.

The following are current issues being discussed within the engineering education community.

Recently, the President’s Jobs Council, a council of U.S. business leaders, was tasked by President Obama to develop a set of recommendations to create U.S. jobs in the short term and improve the nation’s economic competitiveness over the long term. The Jobs Council has encouraged U.S. engineering deans to increase the number of students their schools graduate by 10,000 annually (Jobs Council 2011). While there are calls from computer and software companies that more graduates are needed to fill current openings, the perception of a need for additional engineering graduates is not shared by all (Lynn and Salzman 2011). Engineering graduates continue to enjoy higher wages, on average, than their peers in other fields soon after entering the job market, but salaries do not increase as rapidly in engineering as in other fields, and, by mid-career, engineers are typically receiving wages that have fallen behind wages in managerial occupations and among health care professionals (Carnevale, Smith, and Melton 2011).

There is an ongoing debate on what should be the terminal professional degree for engineers. Currently, the bachelor's degree is required before someone may take a licensure test to become a professional engineer. Some argue that more education should be required before a prospective engineer may take the licensure test, and a master's degree should be the terminal professional degree for engineering.

The increasing diversity in engineering in the United States has been a topic of debate over the last 30 years. Certain groups are underrepresented in engineering, including women, African Americans, Native Americans, and Hispanics. One of the strongest arguments for diversity in engineering is that a diversity of views and perspectives is needed to design quality products that fit the needs of multiple users. For example, women are underrepresented in engineering, and products that are developed by men do not always take into account a woman's perspective such as a bus design that does not have sufficient space to allow a baby carriage to be brought on board. Increasing diversity, the argument goes, would improve product design.

A recent strategy to increase diversity in engineering is to raise the number of minority students who are capable of studying engineering when they arrive at college, meaning that the students have already taken all prerequisite classes. The strategy involves engaging students during middle school to make them more aware of what engineers do, increase their interest in engineering, and help them understand that they should take advanced mathematics and science courses during middle school so they can take the advanced mathematics and science courses during high school and become prepared to study engineering when they begin college. Waiting until high school or college to engage students in engineering is too late because many underrepresented students do not know they must take advanced mathematics and science classes.

Future government policies in engineering education

The United States does not have a system of central planning; for example, there is no direct planning on the number of engineers that should be produced by the discipline annually. However, two organizations that approximate the provision of a vision of engineering education in the United States are the Office of Science and Technology Policy (OSTP) and the National Academy of Engineering (NAE).

The OSTP was established by Congress in 1976 with a broad mandate to advise the president and others within the executive office of the effects of science and technology on domestic and international affairs. Since the OSTP makes recommendation on science and technology policy and not engineering specifically, engineering falls under science, technology, engineering, and mathematics (STEM).

According to two recent reports released by the OSTP, the number of qualified primary and secondary faculty in STEM education should be raised by improving STEM education among undergraduates so that people who go on to become faculty understand science and are able to teach it effectively in primary and secondary education. The states are also encouraged to develop STEM-related educational standards, including primary and secondary education standards for engineering, and to encourage incentives for high-quality STEM faculty.

The NAE was founded in 1964 as a private, independent, nonprofit institution providing engineering leadership. The mission of the NAE is to advance the well-being of the nation by promoting a vibrant engineering profession. The NAE is a member of the National Academies, founded in 1863 during the administration of President Abraham Lincoln. According to a recent report released by the NAE, engineering schools should adopt more flexible and creative approaches to teaching engineering to undergraduates, ABET evaluations should encourage innovation and experimentation in curricula, more educational research in engineering should be conducted, and engineering schools should help improve mathematics and science education at the primary and secondary levels.

The United Kingdom

Saori Imaizumi, the World Bank

Background

In the United Kingdom, the importance of engineers was first recognized through the establishment of the Corps of Engineers in 1717. Later, in 1818, the Institution of Civil Engineers was formed to recognize the contribution of engineering to civil society. At the end of the Industrial Revolution, the Institution of Mechanical Engineers was established, in 1847, and the use of electrical telegraphy led to the creation of an Institution of Electrical Engineers in 1871. Currently, 115 institutions offer engineering courses leading to bachelor's degrees and above. A major characteristic of engineering and technology education in the United Kingdom is the fact that curricula are closely allied with industry, and courses provide various opportunities to work on research projects and seek industry placements.

The engineering sector has been growing. It generated £1.15 trillion in turnover in the year ending March 2010, 24.9 percent of the turnover of all businesses in the United Kingdom. The sector also employed 5.6 million people across 551,520 enterprises (Kumar and Randerson 2011). The United Kingdom is the seventh-largest nation in terms of manufacturing output in the world, behind the United States, China, Japan, Germany, Italy, and France. In 2010, 2.5 million people were employed in U.K. manufacturing, representing 10 percent of all employees (Kumar and Randerson 2011).

As a reflection of the high demand for engineers, the salary of engineers is also competitive. The approximate mean salary for engineering technicians and craftsmen is £26,440, which is higher than the 2009 U.K. gross median average salary of £25,900 and the median salary among 22- to 64-year-olds without a degree (£18,000) (Kumar and Randerson 2011). The mean starting salary among graduates in engineering and technology was the fourth-highest salary (£24,953), following medicine and dentistry, business and administrative studies, and combined subjects (Kumar and Randerson 2011).

On the other hand, there is a lack of skilled workers, although there is a demand for studying and pursuing a career in engineering. In a recent National Employer Skills Survey for England, 20 percent of manufacturers reported skill gaps, and 31 percent of all high-technology manufacturing firms were recruiting people from outside the United Kingdom owing to a lack of qualified local personnel. In regard to the demand for engineering education, according to the 2011 annual Engineering and Engineers Brand Monitor survey, 61 percent of the general public considers engineering a desirable career (EngineeringUK 2011). Among both the 17–19 and the 20+ age-groups, men (50 and 67 percent, respectively) were significantly more likely than women (29 and 58 percent) to view an engineering career as desirable. Respondents in the 20+ age-group tend to consider engineering desirable because they see it as a good profession or career (78 percent) or because it is challenging (71 percent).

To promote engineering education and professions, EngineeringUK, an independent, nonprofit organization, has been holding engineering career–related events to attract and inspire future engineers. They organize two events, the Big Bang Fair and Tomorrow's Engineers, every year. At the March 2011 Big Bang Fair, for instance, EngineeringUK welcomed 29,000 people and over 150 organizations that shared their experiences in engineering careers.

Because of this high demand for engineers and the engineer–career-friendly environment, the country is increasing the number of engineering graduates constantly. Even within STEM, engineering and technology account for the second-greatest production of graduates. Table 3 shows the number of first or professional degrees achieved in STEM subjects. Both the number of graduates and the change over one year for engineering and technology are the second-highest such results.

Table 3: Number of First Degrees Achieved in STEM, All Domiciles, 2002/03–2009/10

Degree	*2002/03*	*2003/04*	*2004/05*	*2005/06*	*2006/07*	*2007/08*	*2008/09*	*2009/10*	*Change, %* *Average annual*	*Total*
Biological sciences	23,725	25,955	27,200	27,840	29,095	31,185	30,720	32,185	4.8	35.7
Physical sciences	12,480	11,995	12,530	12,900	12,480	13,015	13,510	13,795	2.1	10.5
Mathematical sciences	5,100	5,395	5,270	5,500	5,645	5,815	5,980	6,470	8.2	26.7
Computer science	18,240	20,205	20,095	18,840	16,445	14,915	14,035	14,255	1.6	−21.8
Engineering and technology	19,455	19,780	19,575	19,765	19,900	20,420	20,805	21,955	5.5	12.9
Total STEM	79,000	83,330	84,670	84,845	83,565	85,350	85,050	88,660	4.2	12.2
All subjects	283,280	292,090	306,365	315,985	319,260	334,890	333,720	350,860	5.1	23.9
STEM proportion of all degrees, %	27.9	28.5	27.6	26.9	26.2	25.5	25.5	25.3	−0.8	−9.3

Source: Based on HESA data.

The institutional structure and system in higher education

In the United Kingdom, all higher education institutions are public, with the exception of one private university, the University of Buckingham. Higher education consists of a three-year bachelor's degree, a one-year master's degree, and a three-year doctoral degree. Engineering courses are taught at various levels, including vocationally related qualifications, diploma, further education, and higher education. The institutions that offer a bachelor's degree or above are categorized among the higher education levels. These are within the scope of this study.

Financing mechanism

In the United Kingdom, all institutions are state funded through three Funding Councils, which are separately established for England, Scotland, and Wales. Each university receives funding from Funding Councils in different proportions, starting from less than 25 percent (Blom and Cheong 2010). With total income of £21.3 billion and expenditure of £21.0 billion, the higher education sector remains in balance for now. The mean average income among institutions is £110 million. Among these institutions, 11 receive less than £10 million in income, and 45 receive more than £150 million. The United Kingdom spends 0.8 percent of gross domestic product (data of 2004) against an OECD average of 1.0 percent, an average in Japan of 0.5 percent, and an average in the United States of 1.0 percent. Although no institution is in financial difficulties, cost-reduction measures have been taken up, ranging from reorganization to collaboration, redundancy and capital expenditure deferral.

Quality assurance and accreditation

The origin of quality assurance in engineering education goes back to the mid-1950s when the demand for a central agency to promote standards in education and training emerged. This led to the establishment of the Council of Engineering Institutions in 1964. Because of growing criticism of the council's performance during the 1960s, the Engineering Council was established in 1982. It had a governing body composed of qualified engineers, who were in the majority, and individuals linked with engineers in industry and elsewhere. Since then, the Engineering Council has been monitoring the quality of engineering courses through a rigorous review process.

The Engineering Council grants accredited status to institutions providing degrees, and it grants approved status for primary vocational qualifications. During the approval process, the council looks at overall design, coverage, and assessment strategies and seeks evidence that satisfactory quality assurance arrangements are in place. The Engineering Council Examination also provides the means to measure the professional qualifications of engineers as chartered engineers. Since 2001, the test has been administered by City and Guilds, a vocational education organization.

The U.K. Standard for Professional Engineering Competence, published by the Engineering Council, sets a competence framework for engineering professionals.[1] The standard enables individuals and employers to find out whether they or their staff can meet the requirements, and it explains the steps necessary to achieve professional registration with the council.

Major issues and challenges

There seem to be three challenges in the current engineering education system in the United Kingdom. The first challenge is the acceptance and encouragement of novelty in program design. Although accreditation is intended to encourage innovation in program design, articulating the requirements so as to accept novel programs, while keeping to quality standards, is not straightforward.

The second challenge is the shortage of qualified faculty who can teach science and mathematics. According to the census conducted by the Department of Education in schools maintained by local authorities and in academy schools, a quarter (26 percent) of faculty who teach mathematics do not have a relevant post–A-Level qualification. The government is trying to recruit more teachers with the appropriate qualification and increase the retention rate among mathematics, physics, and chemistry faculty. By 2014, the government is aiming at achieving a 25 percent rate of physics specializations and a 31 percent rate of chemistry specializations among science faculty, as well as a 95 percent rate of mathematics specializations among mathematics faculty (Kumar and Randerson 2011).

The third challenge is gender inequality in earnings among engineers, which may discourage women engineers from pursuing careers in engineering. Research conducted by the Department of Business, Innovation, and Skills shows that the average return on an undergraduate

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[1] See "U.K. Standard for Professional Engineering Competence," Engineering Council, London (accessed January 2013), http://www.engc.org.uk/ecukdocuments/internet/document%20library/UK-SPEC.pdf.

engineering degree is around £157,000 among men, but less than £100,000 among women. Nearly two-thirds of the men (64.9 percent) obtain employment with engineering and technology companies. Meanwhile, half (50.8 percent) of the women obtain employment with non-STEM–related companies, compared with only a third (33.5 percent) of the men.

Future government policy in engineering education

Since the onset of the recession, the government's top priority has been to reduce the deficit. Among the measures it has adopted, the government has decided to rebalance the economy by shifting from a heavy dependence on the financial sector to manufacturing. This policy will create more demand for engineers and thus foster engineering education.

Japan

Tsutomu Kimura, National Institution for Academic Degrees

Overview of higher education and the engineering education system

Japanese engineering education at the tertiary level comes under the purview of the general higher education system. The higher education system is composed of national, private, and prefectural universities. Undergraduate courses last four years, and the master's degree usually takes two years. PhD degrees can normally be obtained with an additional three years of study after the master's. The participation ratio in higher education is 52 percent, and the completion rate is 92 percent.

There are 86 national, 589 private, and 90 prefectural universities. The total number of students is 2,835,000, among whom 624,000, 2,080,000, and 132,000 are enrolled at national, private, and prefectural universities, respectively.[1] Around 2,520,000 students are in undergraduate programs, 165,000 in master's programs, 74,000 in PhD programs, and 23,000 in professional programs. Women students account for 40, 30, 31, and 28 percent of the students in these respective courses. These proportions have been steadily increasing in recent years. In the field of engineering, however, the proportion of women students has remained unchanged, at only 11 percent.

In terms of student enrollments, social science has the largest share, at 33 percent (928,000 students), whereas engineering represents 17 percent (489,000 students).

The number of part-time undergraduate students is extremely small. The number of part-time graduate students is relatively large. The number of part-time graduate students is 54,000 out of 262,000 total graduate students, or approximately 20 percent. The majority of part-time students are supported in their education by the companies for which they work.

There are three tiers of technical and engineering education (tiers 1 and 2 deliver higher education):

- Tier 1: four-year universities account for approximately 260 institutions out of the total of 765); the student age range is 18–22.
- Tier 2: five-year colleges of technology (64 in total: 55 national, 6 public prefecture, and 3 private); the student age range is 15–20. There are approximately 60,000 students.
- Tier 3: technical and engineering high schools; the student age range is 12–15. There are 5,500 high schools, 8 percent of which offer technical and engineering courses.

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[1] In this section, basic information, such as the number of students and teachers, is taken from data on the situation in either 2008–09 or 2009–10 unless otherwise specified. There are thus small differences in numbers from the main text, in which the basic information on Japan is taken from data on 2010–11. Note that faculty here is equivalent to department.

Specific governance arrangements in education

a. National universities

Legal status: A national university corporation

Budget:

- *Block grant allocations:* Block grant allocations are controlled by the Ministry of Education, Culture, Sports, Science, and Technology (MEXT) in terms of the total amount of money allocated, but universities can decide how they use the money. Tuition fee levels are strictly controlled by MEXT.
- *Capital grant allocations:* Each year, applications for capital grant allocations undergo a two-stage process; initial assessment by MEXT and then assessment by the Ministry of Finance.

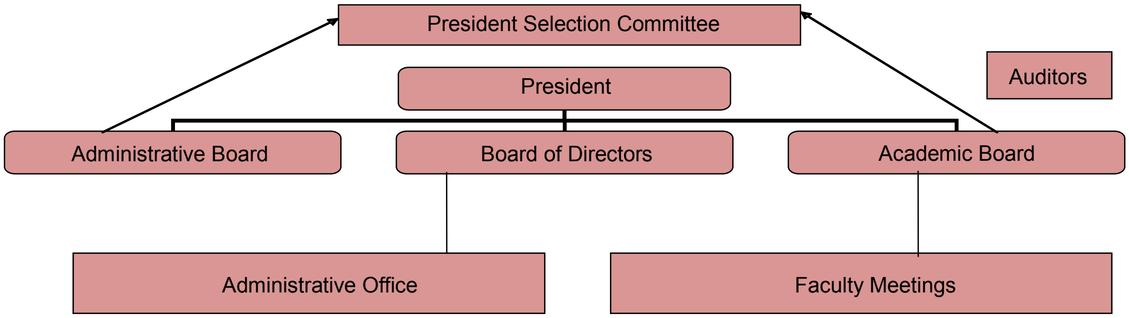
Human resources: Responsibility for contracting, hiring and firing, and for the salary levels of teaching staff and other administrative and technical staff rests with the universities. Each university can decide the total number of its teaching staff. The same applies to staff training, development plans, and funding levels.

Quality assurance system:

- External: See next.
- The internal quality assurance system is now closely linked with the external system as a result of the introduction of a new national evaluation system. All universities are required to submit a self-evaluation report when they receive an accreditation-type evaluation. The evaluation committee checks if a university has a healthy plan-do-check-action cycle. As a result of this procedure, all national universities now have their own internal evaluation systems.

Governance system (Figure 20): This system was introduced when all national universities were incorporated in 2004. The background for this system change is described below.

Figure 20: The Governance Structure of National Universities, Japan



Strategic planning: Strategic plans are in the purview of MEXT. The ministry used to produce detailed strategic plans that tightly controlled the actions of each university, but, in recent years, MEXT only indicates the general framework of its strategic plans so that each university can decide on their own strategic plans within the framework.

b. Private universities

Legal status: A school corporation

Governance system: Similar to that of national universities

Strategic planning: Same as the national universities

Budget: The total amount of public funding provided to private universities is approximately ¥300 billion (around $3 billion). MEXT examines the funding requests of private universities each year and makes an allocation. This funding covers mainly the basic costs of running a university, such as building classrooms for teaching, offices for staff, and research facilities. Private universities can apply for special research grants given by MEXT and other ministries on an equal footing with national universities. Some private universities do not receive any funding from MEXT. The number of these is small.

Private university funding depends heavily on tuition fees. Tuition fee levels vary considerably. Final fee levels must be approved by MEXT. Generally speaking, the ratio of private to national university tuition is 1 to 3 in the social sciences, 1 to 4 in engineering, and 1 to 15 or 20 in medicine.

Human resources: The situation is similar to national universities; however, among national universities, the block grants that cover staff salaries are determined by MEXT, while, among private universities, the main source of funding for staff salaries is tuition fees. In this sense, the control exercised by MEXT is weaker over private universities relative to national universities.

Quality assurance system: This is exactly the same as for national universities in accreditation-type evaluations. Private universities now have an internal system that is similar to the system for national universities.

c. Public (prefectural) universities

Legal status: The status is as either a university corporation or a type of organization run by local governments, such as a highway corporation or a housing corporation.

Governance system: For university corporations, the system is similar to that of national universities. For organizations under local governments, a senate—consisting of the president, deans, and representatives elected through meetings among professors—makes decisions on important issues.

Strategic planning: The local government decides on strategic plans within the framework put forward by MEXT. This type of public prefecture university has less freedom and autonomy than national universities.

Budget and human resources: The responsibility rests with local governments. These universities receive nearly all their public funding from local governments. They can also apply for special research grants on an equal footing with national and private universities.

Quality assurance system:

- *External:* These universities have to receive an accreditation-type evaluation once every seven years. The evaluation is similar to that for national and private universities.
- *Internal:* Because of the new framework for external evaluations (see above), these universities have developed internal systems similar to those of national and private universities.

d. National colleges of technology

In engineering, colleges of technology, particularly the national colleges of technology (*kōsen*), are now considered extremely important in maintaining Japan's position as one of the strongest countries in manufacturing in the world.

In 2004, 54 national colleges of technology were combined into a single college of technology corporation, which has a similar governance structure to that of the national university corporation. Each college, however, is allowed limited autonomy. Important decisions are made solely by a principal, the top figure among teaching staff. According to the School Educational Law, the only duty of these colleges is teaching. As a result of this mechanism, the quality of the teaching is high, for which OECD reviewers have recognized the colleges (for example, see Newby et al. 2009). The total number of students in these institutions is 60,000. The graduates of colleges of technology are extremely well received within industry. Several years ago, when university graduates faced the difficulty of finding employment, graduates of colleges of technology enjoyed the situation that even the lowest average rate of job offers they received across individual colleges was 8 per graduate.

Recent reforms

The University Council, which was organized by MEXT, published a report on the future of higher education in Japan. In the report, "Creating Universities with Marked Individual Characteristics in Competitive Environments," the council stated that, under the current system, national universities in Japan would not be able to achieve the goal expressed in the title and that a new system should be introduced to urge universities forward (University Council 1998). This led to long discussions across sectors on an eventual change in the status of national universities. The discussions concluded in 2003 that universities should become incorporated.

The following were the main elements of the change in the system:

- Deregulation of management through incorporation
- Concentration of authority in each university president
- Target-based indirect control by the government: each university was to describe targets for a midterm period (six years); the MEXT evaluation committee would check if the targets had

been achieved; MEXT determines the relevant block grant based on the performance of each university

Incorporation increased the freedom of national universities in several ways.

a. Finance

- The introduction of block grants (formula-based, plus item-based)
  - Some budget controls remain (described above under the main elements of the change in the system)
  - Internal and external audits are reinforced
- Separate funding for capital grants
- Tuition fees are fixed, but with an allowance for differences; so far, no national universities have taken advantage of the allowance; the tuition fees are the same for all national universities
- Freedom in acquiring and using nongovernmental resources

b. Staffing

- Change in the legal status of staff to nongovernmental employee
  - Freedom from government regulation
  - Repeal of the legal guarantee of the faculty's and senate's authority in matters concerning academic personnel

c. Organization

- Establishment or dissolution of fundamental academic units such as departments, postgraduate schools, and research institutes is stipulated in the midterm plan
- The number of student places in basic academic units is stipulated in the midterm plan

The main features of governance include the following:

- The minister of MEXT appoints the auditors
- Each president appoints all university staff, except auditors
- Only the presidents can legally represent universities and corporations
- The minister of MEXT appoints or discharges presidents based on the decision of the university presidential selection committee
- The inclusion of outside persons is required among auditors, directors, and administrative board members

The main features of the target-based controls include the following:

- Target-setting is based on the university's draft targets: MEXT determines only the rough guidelines and checks if the targets are reasonable.
- Targets and plans are comprehensive: It is not necessary for each university to set detailed midterm targets and plans. The general targets are broken down into detailed yearly plans. Because the MEXT evaluation committee assesses the performance of each university once every six years on the basis of midterm targets and plans set by each university, it is rather difficult to assess this performance properly.

- Evaluations are carried out by the MEXT national university evaluation committee.
- The evaluation of teaching and research is entrusted to the National Institution for Academic Degrees and University Evaluation.
- The results of evaluation affect funding.

The impacts of incorporation have included the following:

- A reduction in block grant expenditures from ¥1.2 trillion (2004) to ¥1.2 trillion (2011)
- Steady progress in improving operational efficiency
- A reduction in operational costs from ¥1.6 trillion (2004) to ¥1.5 trillion (2009)
- Strategic resource allocations are carried out on the initiative of presidents: funding (at all 86 universities); decisions on the number of staff and their respective salaries are at the discretion of the presidents (at 82 universities), including the introduction of special salaries to cover the cost of inviting high-profile researchers and tuition waivers for students who show extremely high performance
- The promotion of a fixed-term employment system for academic staff: the number of fixed-term staff rose from 516 (in 2000, before incorporation) to 8,816 (in 2006 at 81 universities) and to 15,591 (in 2009 at all 86 universities)
- Attempts to enhance the quality of teaching and to participate in the life-long learning community: a strict grading system (the grade point average system) was used at 7 percent of institutions in 2000, but 68 percent in 2009; the incidence of evaluations of the teaching performance of academic staff rose from 28 to 88 percent in 2000–09; the number of adult students following graduate courses increased from 4,641 to 7,395 over the same period
- The introduction of the use of funds from external sources: donations rose from ¥49.2 billion to ¥72.7 billion in 2000–09; long-term loans were negotiated at banks at five universities for the construction of a veterinary hospital, student dorms, an international house, and so on
- The active promotion of university-industry links: investment in joint research increased from ¥11.2 billion to ¥34.7 billion in 2001–09 and, in commissioned research, from ¥35.1 billion to ¥132 billion in 2001–09; the number of patent applications increased by a factor of 2.3 in 2001–09, and patent royalties rose by a factor of 3.1; 3.5 times more start-up companies were established from 2001 to 2008.

Engineering

a. The history of the development of engineering

The promotion of industry was the first priority of the new government created immediately after the Meiji Restoration (1868). This required high-quality engineering education. Because no Japanese instructors were available, the prime minister contacted personal acquaintances in the United Kingdom to seek a proper faculty. His request reached William John Macquorn Rankine, father of modern thermodynamics, at Glasgow University. Rankine recommended one of his students, Henry Dyer, to the Japanese government. Dyer was an extremely bright engineer and only 25 years of age.

In those days, there was no academic discipline called engineering in the United Kingdom. There was only the practical application. Because Dyer did not believe this was an appropriate approach, he decided to found an engineering school in Japan. There, he integrated the practice-oriented British style with the highly academic European style. The engineering school was opened in 1873 as the Imperial College of Engineering. Dyer started a six-year course of study at the school according to the following structure:

- Years 1 and 2: mainly classroom teaching
- Years 3 and 4: 50 percent experiments and practical experience
- Years 5 and 6: full internship at state-run factories or other jobsites

The school was enormously successful, and it produced many innovative engineers who contributed to the modernization of Japan. It was greatly influenced by British engineering education. It remained independent for only 12 years, becoming a part of Tokyo University in 1885. Responsibility for the school was shifted from the Ministry of Trade and Industry to the Ministry of Education. This ministry altered the school's system: coursework was reduced to four years, and the practical elements in the curricula were cut substantially. As a result, engineering as an academic discipline produced fewer and fewer high-quality engineers. This trend is still evident today.

In 2005, the Japan Accreditation Board for Engineering Education became a signatory member of the Washington Accord, an international accreditation agreement on professional engineering academic degrees. On that occasion, the review team commented that most Japanese engineering programs emphasize the learning of relevant scientific principles more than the application of those principles in a design context, making Japanese engineering education somewhat different from that found in many of the countries of the Washington Accord. The review team suggested that this meant that, although the end result is clearly highly educated engineering graduates with excellent experience in research, the Japanese graduates probably have little hands-on engineering experience.

In 2012, when new recognition criteria were adopted, the accreditation board began placing a greater focus on the design ability of engineering graduates.

b. Number of faculty and students

The traditional structure of faculties at Japanese universities was based on a chair system. Typically, in engineering, one faculty at most of the major universities had six chairs, and each chair was responsible for teaching and research in a particular discipline. One chair represented a full professor, an associate professor, two research associates, and one technician. This system lasted for about 120 years, but, around 2000, the Ministry of Education started to allow universities to introduce non-chair systems. This was necessary because of dramatic changes in the direction of research, the emergence of a number of new research areas, and the requests of universities to be allowed to establish different interdisciplinary faculties.

Currently, approximately 260 faculties exist in engineering fields at 166 universities (out of a total of 765): among the 86 national universities, 57 have such faculties; the respective count at the 90 public universities is 18; and at the 589 private universities, 91.

The number of undergraduate students who are participating in an engineering discipline is 410,000, representing 17 percent of all such students. The number of students pursuing a master's degree is 65,000 (39.4 percent). This is by far the largest share among all the disciplines. Social science is second, with 19,000 students. The number of PhD students is 14,000 (18.6 percent of the total), second after medicine.

c. The typical structure of curricula

Until 1991, there was a strict requirement that the minimum number of credits necessary for a bachelor's degree—124—should include at least 76 credits in specialized subjects, 36 credits in general education subjects, 8 credits in foreign languages, and 4 credits in physical education. As long as a university observes the regulation on the 124 total credits, it is free to structure its curricula. This has led to education reform at Japanese universities, producing a variety of unique curricula structures. Table 4 shows the typical curriculum at a small university oriented toward science and engineering.

Table 4: Typical Curriculum, Small Science and Engineering University

Required subject areas	*Subjects*		*Credits*
Liberal arts	Non-science	a. Humanities, sociology, literature, law, economics, and so on	Minimum 18, including at least 4 in category a
		b. Interdisciplinary subjects, civilization and culture	
	International communication	Chinese, English, French, German, Russian	Minimum 14: 10 English + 4 in others or 8 English + 6 in others
	Health and sports	Health science, physical education	3
Basic science and engineering	Calculus, algebra, physics, chemistry, biology, earth and space science, descriptive geometry		Minimum 16; the requirement varies by faculty
Specialized subjects			As specified by each faculty
Graduation research project			6–14, varies by faculty
Total			Minimum 124

d. Government visions, goals, and policies in engineering education

The University Council (1998) identified the roles and functions of universities as follows:

- Pursuing world-class research and education
- Training highly skilled professionals
- Training professionals in a wide range of areas
- Fostering high-quality general education
- Carrying out education and research in specific areas (sports, the arts, and so on)
- Promoting a life-long learning community
- Contributing to society and service to society

These roles and functions apply equally to engineering universities and universities with engineering faculties. The council stated that each institution is free to choose one or more of any of these functions. Following the council's report, MEXT policies became targeted on accelerating a differentiation in the roles and functions of each institution.

An accreditation-type evaluation system was introduced in 2004. All universities in Japan have to be evaluated once every seven years. Three evaluation agencies—the National Institution for Academic Degrees and University Evaluation, the Japan University Accreditation Association, and the Japan Institution for Higher Education Evaluation—are responsible for carrying out the evaluations. These agencies have been authorized by MEXT, and their capabilities are monitored by the Central Council for Education. The evaluation covers mainly assessments of teaching quality. The results of the accreditation-type evaluation do not affect funding except in cases of illegal conduct. Each university is free to choose any one of the three evaluation agencies.

In addition to these evaluations, all national universities must undergo a comprehensive evaluation once every six years by an evaluation committee organized by MEXT. The National Institution for Academic Degrees and University Evaluation carries out the evaluation of teaching and research. This scheme was introduced in 2004 following the incorporation of national universities. The evaluation results affect 8–9 percent of each university's block grant allocation. The impact of this varies from institution to institution. Thus, smaller universities with less alternative funding streams will be affected more than universities with more diversified funding sources.

As a result of the decline in the size of the youth population, 40–50 private universities are now facing serious economic problems. They may go bankrupt. In such cases, the priority will be to transfer the students in these universities to other universities to ensure minimal disruption in studies.

Russian Federation

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Overview

In modern Russia, engineering education is realized through secondary vocational and higher education programs (International Standard Classification of Education [ISCED] 1997, levels 5B and 5A) and also postgraduate (PhD) programs (ISCED 1997, level 6).[1] In 2010, there were 2.5 million students in Russia who were studying through engineering programs. Of these, 61 percent corresponded to ISCED 1997, level 5A; 37 percent, level 5B; and 2 percent, level 6. Engineering education is mostly received through public educational institutions; the share of private institutions represented in the overall number of students is low, only about 2 percent (Table 5). At the same time, secondary vocational institutions are engaged in educating future engineers to an even greater degree than higher education institutions. While the percentage of engineering students in the overall number of students at higher education programs was a little less than a quarter (22 percent), the same indicator for secondary vocational programs was twice as much (44 percent). However, the proportion of postgraduate students who are preparing theses for the engineering branches of science is significantly higher, 35 percent.

Table 5: Number of Students in Engineering Programs, Russian Federation, 2010

Educational level	*ISCED 1997 level*	*Students, total*	*Engineering students among all students, %*	*Students at public institutions among all engineering students, %*
Secondary vocational	5B	930,116	44	98
Tertiary education	5A	1,536,447	22	98
Bachelor's programs	5A	135,726	22	91
Specialist programs	5A	1,369,200	22	98
Master's programs	5A	31,521	30	100
PhD programs	6	54,994	35	100[a]
Total	5–6	2,521,557	27	98

Source: Data of the Federal State Statistics Service of the Russian Federation.
a. Approximate value according to our peer review.

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[1] Only candidate of science (not doctor of science) programs. Note that the candidate of science degree is a Russian analog to the PhD. For the ISCED 1997 classification, see UNESCO (1997).

The percentage of bachelor's and master's programs in engineering areas is extremely small.[2] This reflects a common trend in Russian education. In 2003, Russia joined the Bologna Process, which is designed to ensure comparability in the standards and quality of higher education qualifications among European countries. This presupposes a gradual transition from specialist programs to the two-level higher education system, or 4 + 2, that includes bachelor's and master's programs. However, the attitude of the Russian public to this reform has been hesitant. The administrations and faculty at many higher education institutions, especially engineering, have opposed the transition. The mass increase in the intake of students in bachelor's programs at the expense of a decline in admissions of specialist students was implemented by the Ministry of Education and Science only in 2011. Since 2009, a rapid expansion in master's programs has been mapped out, but this stage of higher education is still poorly represented.

There are 28 aggregative groups of specialties in secondary vocational and higher education programs. Among these, 16 may be associated with engineering.[3] Seven of these cover 72 percent of the overall number of engineering students; transport (17 percent), architecture and building (17 percent), computer science (11 percent) are among the top three.

Recent trends in Russian engineering education

Engineering education programs were quite popular and filled a need in Russia in the recent past. The high demand for engineering programs was dictated by the structure of industry in the Soviet Union. In 1990, shortly before the disintegration of the Soviet Union, half of the Soviet labor force worked in industry, building and construction, and transport and communications, which all obviously include engineering. By 2010, the share of people employed in these areas had declined by 14 percent relative to 1990, while the overall decrease in the size of the labor force had been 10 percent. This led to a reduction in the employment rate in these areas by 36 percent.

However, engineering education institutions did not make adjustments in educational programs in line with the new economic structure. Because of the transition from the planned economy to the market, many industrial enterprises and organizations were closed and the demand for engineers in the labor market dropped dramatically at the beginning of the 1990s. Many graduates from engineering programs faced difficulties finding positions in engineering during these years. Some engineering specialties actually lost competency in the labor market, and only a quarter of graduates were ensured of workplaces.

Recently, however, the higher education system has been experiencing a boom. Relative to 1990, the number of students in secondary vocational programs in 2010 was practically the same, but

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[2] In Russia, higher education programs consist of three stages: bachelor's (four years), master's (two years), and specialist (five years and, sometimes, for example in medicine, six years). Relative to doctorate programs elsewhere, the level of specialist programs is significantly closer to the level of master's programs.

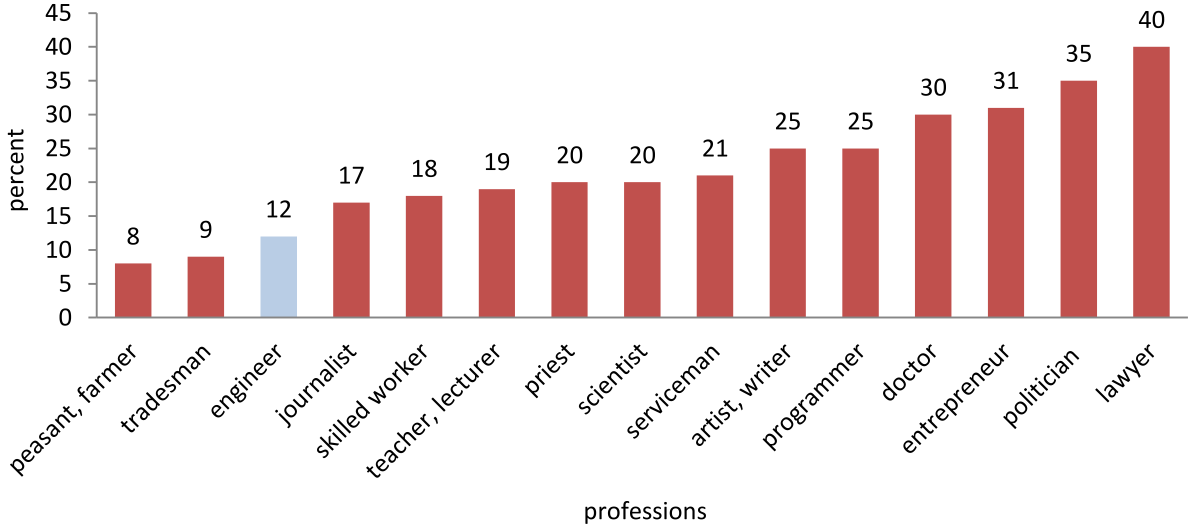
[3] The aggregative specialties in engineering are (a) geodesy and land management; (b) geology and mining; (c) energy, power machine building, and electrical engineering; (d) metallurgy, mechanical engineering, and materials processing; (e) aircraft and space-rocket equipment; (f) arms; (g) marine equipment; (h) transport; (i) instruments and optical equipment; (j) electronic and radio engineering; (k) automation; (l) computer science; (m) chemistry and biotechnology; (n) wood products and timber processing; (o) provision and textile technology; and (p) architecture and building.

the number of students in higher education programs had increased by 35 percent. Higher education programs are becoming more popular, and this has affected the dynamics in the number of engineering students. A larger increase in the humanities and, especially, in law and economics has been crowding out engineering programs, and the share of students in engineering declined from 40 to 22 percent. Though engineering graduates are now facing less difficulty finding jobs compared with the early 1990s, engineering jobs are still not as available as they were in the Soviet era.

Today, the engineering professions are not held in such high regard as earlier. This is shown by the results of public opinion surveys (Figure 21). According to these data, only 12 percent of respondents held the engineering profession in high regard. At the same time, only 10 percent of respondents among 18-year-olds agreed with this opinion. Among students at engineering universities, only one-third do not regret their choice of educational program and would make the same choice again if the opportunity should arise.

Figure 21: Prestige of Engineering Professions, Russian Federation, 2009

share of answers, %



Note: The survey question was "in your opinion, peoples of what professions are mostly respected now in Russia?" The sum of the answers is higher than 100 percent because respondents could choose up to five professions.

Quality assurance, governance, and accreditation

The development of education, including engineering education, is tied up with the emergence of the modern system for rating the quality of education based on objective, transparent measures and social participation. A great deal of attention is now being paid to the quality of the training in higher education institutions.

In Russia, quality is still an issue. As part of the Monitoring of Education Markets and Organizations Project, the Higher School of Economics carries out an annual survey of a pool of employers (heads of enterprises) to estimate the quality of graduate training.[4] According to the pool data from industrial, transport, communication, and architecture and building enterprises, the average mark in 2010 for professional knowledge among graduates of secondary vocational schools and higher education was 3.7 out of 5.0, while, for learning capability in the workplace, it was 4.0.

In Russia, quality assurance is regulated according to state educational standards, licensing, and accreditation procedures. The formal requirements of the quality rating system in education rely on state accreditation indicators. The accreditation procedure certifies, for a certain period, the correspondence of educational program content and quality to the state educational standards and leads to the recognition of the right of educational institutions to award state diplomas (certificates of degree) to their graduates. Among the aggregative specialties, the large majority of secondary vocational and higher education programs are accredited. In 2010, 96 percent of the programs at public institutions and 87 percent of the programs at private institutions were accredited.

Public accreditation also exists. The process is conducted by public and professional organizations, unions, and associations. Public accreditation is important for the reputation of an educational institution, but it cannot replace state accreditation and does not involve any state guarantees.

Issues and challenges

a. The adverse selection problem

The low demand for engineers on the labor market and the unpopularity of engineering professions lead to an adverse selection problem in the enrollment of students at secondary vocational and higher education institutions, that is, the undesirable results that arise because the low demand and unpopularity push the better students to avoid the engineering professions. Thus, for example, among university entrants who were accepted in 2010 at higher education engineering programs for budget-financed seats, the average score on the unified state examination (USE) was only 60 out of 100, with a range from 52 to 62 depending on the aggregative specialty.[5] This is lower than the overall average of 63 among entrants accepted for budget-financed seats at all higher education programs. It is quite significant that the average USE scores for medicine in higher education programs was 74 and, for economics and management, 70.[6]

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[4] See "Monitoring of Education Markets and Organizations," National Research University Higher School of Economics, Moscow, http://www.memo.hse.ru/en/.

[5] The education of students with budget-financed seats is financed through the public budget. The USEs are final examinations in secondary education programs (ISCED 1997, level 3). They are carried out throughout the country. According to admission rules that went into force in Russia several years ago at secondary vocational and higher education institutions, the examinations are recognized as preliminary.

[6] The data are based on university entrant background-level monitoring that was carried out by the National Research University Higher School of Economics, along with the RIA Novosti news agency, at the request of the Public Chamber of the Russian Federation in 2010 (Dobryakova and Andrushchak 2010).

Unfortunately, there are no data on the USE scores among secondary vocational program entrants. Nonetheless, it is safe to say that secondary vocational programs enjoy considerably less popularity among young people relative to higher education programs. Because entrants who achieve higher USE scores more often apply at universities, the average USE scores of the students accepted at secondary vocational institutions in engineering are most likely lower than the average scores among university entrants.

The adverse selection problem that arises in the admission of engineering college or university students may be aggravated in the near future because of demographic decline. According to estimates of the Federal State Statistics Service of the Russian Federation, the share of the population at age 17–30 will continue to decline and, by 2020, may have dropped by one-third relative to the level of 2010.

b. The obsolete research environment

The material and technical deterioration and obsolescence at educational institutions generally are also affecting engineering education in Russia. Modern laboratory facilities are one of the most important components of the teaching process in engineering courses at colleges and universities. This requires significant financial resources. The lack of financing to maintain and upgrade laboratory facilities represents an obstacle to the education of future engineers, who, moreover, generally already have few opportunities to gain practical knowledge and experience in the use of modern technologies.

The Soviet legacy has left a mark on the development of engineering education, which, in Russia, tends to be focused on narrow training methodologies. Because of this, the shortage of college and university entrants in engineering education (especially students who are well grounded) is fostering a reliance on obsolete technologies and generating a lack of receptiveness to innovation among engineering graduates (Dobryakova 2009).

c. Weak links with industry

The private sector is not offering incentives for the modernization of the engineering education system in Russia. A major part of the corporate sector has become oriented toward gaining short-term profits. Private enterprises mostly prefer to import new technologies and means of production from abroad or continue to use the capacity established during the Soviet period. For this reason, the corporate sector has not demonstrated a particular interest in training its own engineering personnel or developing its own new technologies.

Institutions of professional education seem, to a large extent, to have lost their links to real sector enterprises, which existed during the Soviet period and were the basis of the narrow specializations. The newly emerging forms of such interrelations are nonsystematic and are insufficient to form a strong specific basis for educational institutions. These various factors all indicate the lack of motivation for a reconsideration of educational activity and a restructuring and modernization of engineering education programs.

The way forward: modernization of the Russian economy

The improvement of engineering system education is a major problem in Russia. A solution would have special significance in the light of any approach to the modernization of the Russian economy. Among the priority directions in Russian economic development, policy makers have emphasized information technology, nanotechnology, new materials technologies and living systems, new methods of motor fuel production, competitive power installation development, new-generation aircraft, energy-efficient engine production (including gas turbine engines), and space technology. It is obvious that efficient efforts within each of these areas are quite impossible without highly qualified engineers, whose training will require the substantial modernization of engineering education. These issues have been discussed by the authorities more than once. Thus, when Deputy Minister of Education and Science Sergei Ivanets recently spoke to the 5th Education Ministerial Meeting of Asia-Pacific Economic Cooperation, held in Gyeongju, the Republic of Korea, on May 21–23, 2012, he emphasized the need for globalized, cooperative approaches to education in the interrelationships among the economies of the Asia and Pacific region.[1] He likewise drew attention to the importance of training personnel according to the specialties that are of interest to these economies.

Despite the problems in engineering education in Russia and the gradual aging of faculty in engineering, as well as in leading institutions of the education system, a range of engineering colleges and universities exist that are able to produce highly qualified engineers for the labor market. The necessity for economic modernization and the greater attention of policy makers to the problems in education, including engineering, provide us with reasons for hope in positive change.

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[1] See "Transcript of the AEMM5: Day two, Gyeongju, Republic of Korea," Asia-Pacific Economic Cooperation, Singapore, http://apec2012.ru/news/20120522/462583866.html.

Brazil

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A brief historical overview

Engineering in Brazil started timidly at the turn of the 18th century. The Portuguese crown provided safety to locals against pirates and foreign attack. The coasts and rivers bordering the Spanish colonies were guarded by the Portuguese army and navy. Engineering then was basically for military uses, and it fundamentally dealt with the construction of fortresses and the development of artillery.

Throughout the 19th century, civil engineering was needed for the development of large urban centers.

By the early 20th century, these centers demanded energy for public and private electrical lighting and the use of electric machinery. Electrical engineering had its debut with the construction of hydroelectric power plants. Nonetheless, the industrialization process was not immediate in Brazil. It was mostly conducted by foreign enterprises that provided complete projects for local implementation with only a modest need for local engineering.

During the second half of the 20th century, Brazil finally engaged in the process of the development of postgraduate studies and research in the university system. Progress has been steady for more than half a century, and Brazil has become an important reference point for research in engineering. The strong interaction with the best universities in the world led to much discussion on modern engineering and engineering education in academic institutions in Brazil. Throughout this period, the abundance of international capital allowed the construction of important infrastructure, especially hydroelectric power plants, roads, bridges, and other large civil structures. This was the golden age of engineering in Brazil. Some engineers who had been managing the construction of these large structures decided to start their own postgraduate programs and became champions of graduate studies in Brazil.

The necessity for local solutions, such as the use of ethanol in the automotive industry and the need to find offshore sources of petroleum, has transformed the role of engineering. By the end of the 20th century, engineering as a vital component in economic growth had become a focus of discussions among the government, schools of engineering, and industry, including the service sector, in Brazil. A strong movement toward entrepreneurship emerged that was responsible for the appearance of several university incubators for small start-up enterprises based on advanced technology. The need for more technological development, particularly in applied science and technology, has changed the scope of research in Brazil.

Schools of engineering in Brazil have followed the trend toward globalization and have become comparable to such schools in other countries. A reform movement in engineering education emerged in the 1980s and 1990s. This led to improvements in quality, the addition of practical and applied disciplines to engineering curricula, and incubators for spin-offs.

The beginning of the 21th century has been characterized by a shift toward a less rigid vision of economic development and a focus on sustainability in both the social and environmental aspects of engineering. Two themes have evolved from this shift: engineering is an important vector of innovation, and it is necessary for infrastructure development in the country. This modern vision has been a focus of Inova Engenharia, a project to modernize engineering and expand the technological capacity of companies in the country. Supported by the National Confederation of Industry (CNI), the project is being executed in partnership with 17 academic institutions and public and private sector organizations.

The current features of engineering education

a. Structure

Institutions of higher education in Brazil include public and private universities. Private universities account for more than 70 percent of all students. Only a few private universities are run purely for profit, but their number has been growing rapidly. Although some nonprofit private universities rank among the best in Brazil, the quality of public universities is typically considered to be high. Because public universities do not impose direct fees on students and considering the high cost of engineering courses, many private universities do not fill all the places they have available.

b. Issues

The CNI and the Coordination for Enhancement of Higher Education Personnel (CAPES), the federal agency for the support and evaluation of graduate education, have conducted studies to increase the understanding of the economic and social issues hindering the development of engineering in the country. The Brazilian Association for Engineering Education and the National Council for Engineering and Agronomy have participated actively in these studies, which have identified the following issues:

- The internal efficiency of engineering education, in general, is not sufficiently efficient. The average time students take to complete a five-year course is longer than it should be: they usually take six or seven years to complete the programs.
- Many engineering students are not prepared for studies at the higher education level. This is one of the reasons for the efficiency issue. Many of them have to spend one or two years taking remedial courses, mostly in physics, chemistry, mathematics, and even Portuguese. They have difficulty understanding the importance of basic academic knowledge on engineering and fail to complete the remedial courses. As a result, most of the dropouts leave school during the first two years.
- The courses are too theoretical. There is room for improvement in pedagogy, and faculty members need to provide students with both theoretical strengths and hands-on skills in engineering.
- One of the most difficult problems facing engineering education in Brazil is the unpopular image of the engineering profession in society. This is a barrier to attracting talented preuniversity students to the engineering disciplines. Hence, unlike India, Korea, Singapore, and Taiwan, China where the profession of engineering is well respected in society, only a limited number of talented students are seeking places in schools of engineering in Brazil. Although the number of students in engineering has been growing slightly recently, only 5

percent of all university students are enrolled in engineering disciplines. In contrast, for example, the share in Korea is about 27 percent.

- Brazil is an important producer of primary commodities, such as minerals, petroleum, and grain. In Brazil, the production of primary commodities has become economically important, and engineering is in demand to develop more efficient processes for the production of primary commodities in difficult environments. A typical case is the deep sea production of petroleum, which requires special processes. Extensive research has been carried out by Petrobras, the Brazilian petroleum company, in collaboration with universities, particularly schools of engineering. Another example is exploration for minerals, which requires the large-scale transportation of ore, which is associated with complex problems in logistics. The efficient production of grains in various parts of Brazil has also been the result of important research and innovation in the related production processes. The Brazilian Agricultural Research Corporation and several universities have been involved in the studies.

Although high technology is needed to produce these commodities efficiently, there is usually less value added than in secondary and tertiary industries. Brazilian society is becoming less tolerant of the country's effort to promote economic development through the production of primary commodities. Some in the industrial sector believe that this development effort is leading to deindustrialization and are now seeking a paradigm shift to innovations in the development of final products in secondary and tertiary industries.

Recent developments

In response to the issues and challenges, the CNI has proposed the establishment of a national program in favor of engineering with eight strategic axes that aim to improve the quality of engineering education in the country. The program has been presented to the federal government for consideration. The main attribute of this strategic program is the close partnership among industry, schools of engineering, and the government. The following are the eight strategic axes:

- Establish an engineering association and launch a nationwide movement for innovation
- Include industries in the governance structure of a national program favoring engineering
- Fill all the currently idle faculty positions in schools of engineering
- Reduce the drop-out rate in engineering education
- Reduce the time students spend in schools of engineering to five years
- Provide engineering professors with training not only so they understand the new role of engineering, but also so they use modern educational tools
- Review the current curricula of engineering courses, with an eye to enhancing competencies
- Attract young talent to the engineering profession through a strong program beginning in high school and through awareness-raising efforts in civil society

In alignment with the program, the federal government is considering offering 100,000 fellowships for study abroad with a focus on engineering at institutions of higher education. The government is planning to provide funds for 75,000 fellowships, while the private sector is expected to be responsible for the remaining 25,000 fellowships.

At the institutional level, engineering faculty at universities have started providing students with more hands-on skills, in addition to academic skills. The best engineering departments have strong graduate programs. They often promote scientific initiation, that is, they offer undergraduates the opportunity to pursue academic careers through fellowships and positions as research assistants to professors in research laboratories. Recently, scientific initiation has been expanded through a new effort, technological initiation, which focuses on applied engineering in collaboration with industries. Federal and state agencies are financing the scientific and the technological initiations through fellowships for students and research grants for laboratories. Some of the undergraduate students involved in this effort have already created university incubators for small enterprises that have led to many important spin-offs.

The effort to improve the quality of engineering education has been extended to secondary schools. School faculties are being encouraged to use well-established laboratories of physics and chemistry in schools of engineering. Furthermore, secondary school students are being offered the opportunity to work with new technologies and learn about the social relevance of these technologies.

The way forward

Brazil is a unique country among the BRICs in that its history goes back only 500 years. Most of the solutions to national problems were introduced to the former colony by the European colonizers during the first three centuries and by the international community in the last two centuries. Only in the late 20th century did local problems start to be addressed by local engineers. The value of the exports of Brazil is the smallest among the BRICs (about $250 billion compared with $310 billion for India, $530 billion for Russia, and $1.8 trillion for China).

However, Brazil is far behind in the area of innovation and intellectual property, although it is relatively better than India and Russia. It ranks 47th in INSEAD’s 2011 Global Innovation Index compared with China, at 29th; Russia, at 56th; and India, at 62nd. Most of the investment in research is provided by the government, which focuses primarily on petroleum and gas exploration and production. Mechanisms to develop innovation must be designed, and better engineering is only part of the mechanisms that, together, form an ecosystem, including legislation, new facilities for people willing to start enterprises, and a fresh vision for the country.

How many engineers does Brazil need to develop such an ecosystem? The national effort to develop engineering and the sciences in education in Brazil is paying off. Approximately 1,200 PhDs in engineering are produced every year. Brazil is 13th in the world in this regard. Nonetheless, even if the country were to continue to depend on primary commodities, it would still have to double the current output of schools of engineering (in this case, those offering only five-year courses) from about 40,000 engineers per year to at least 80,000, according to the CNI. However, if Brazil were to adopt a more ambitious economic model that depends less on primary commodities and promotes more value added and more knowledge-based products in secondary and tertiary industries, the number of engineers required would be much greater.

The proengineering program designed by CAPES and the CNI highlights the positive externalities in such a model, which has two advantages. Brazil would be able to reduce its dependency on primary commodities, the prices of which often fluctuate unpredictably in the international market. Furthermore, it could become more inclusive once it has created more and better working places. The production of primary commodities will always be part of the Brazilian economy, but it is not inclusive.

China

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Background

Modern engineering was introduced in China in the late 19th century after a series of military defeats convinced the Qing government to modernize the military.[1] However, engineering education did not become systematic until after the establishment of China's first modern universities at the turn of the 20th century. After 1949, engineering education was reorganized when the government transformed the country's early universities into smaller, highly specialized institutions created to meet the demands of industrialization. These Soviet-style institutions grew rapidly, and enrollment increased nearly sixfold between 1949 and 1965, peaking at around one million in 1960 (Li 2009). This expansion persisted until the launch of the Cultural Revolution in 1966, at which point many higher education institutions were closed, and academia stagnated for the next 10 years.

Beginning in the 1970s, economic reforms such as the Four Modernizations emphasized science, technology, and engineering as key to China's economic modernization and development. As a result, the proportion of engineering students in universities rose, reaching a third of total enrollments and lingering between 35 and 40 percent throughout the 1980s and the 1990s (MOE various). By 1998, at the start of the government's mass effort at the expansion of higher education, the number of four-year (undergraduate) engineering students was around 1.1 million (MOE 2000). The number increased by almost 3.5 times over the next decade and, by 2010, had reached close to 4.0 million (MOE 2011).

Higher education: institutional structure and system

Higher education institutions in China tend to be of one of two types: comprehensive (defined by the Ministry of Education as any institution with departments of both humanities and science-engineering) or specialized. Of the latter, around 46 percent are institutions of science and technology, that is, institutions that offer primarily majors in engineering or the basic sciences. In 2010, there were 834 such institutions, in comparison with 568 comprehensive universities (MOE 2011). The number of enrollments at each institution of science and technology varies from under 300 to over 30,000. However, the majority of schools have a student body of between 5,000 and 10,000 students (MOE 2011).[2]

Today, the percentage of students in engineering remains high, despite a gradual decline over the past 10 years (Figure 22). Engineering students represent about 32 percent of all undergraduate students in China, and the percentage is higher in elite universities relative to nonelite universities. A similarly high proportion of master's degree students are studying engineering

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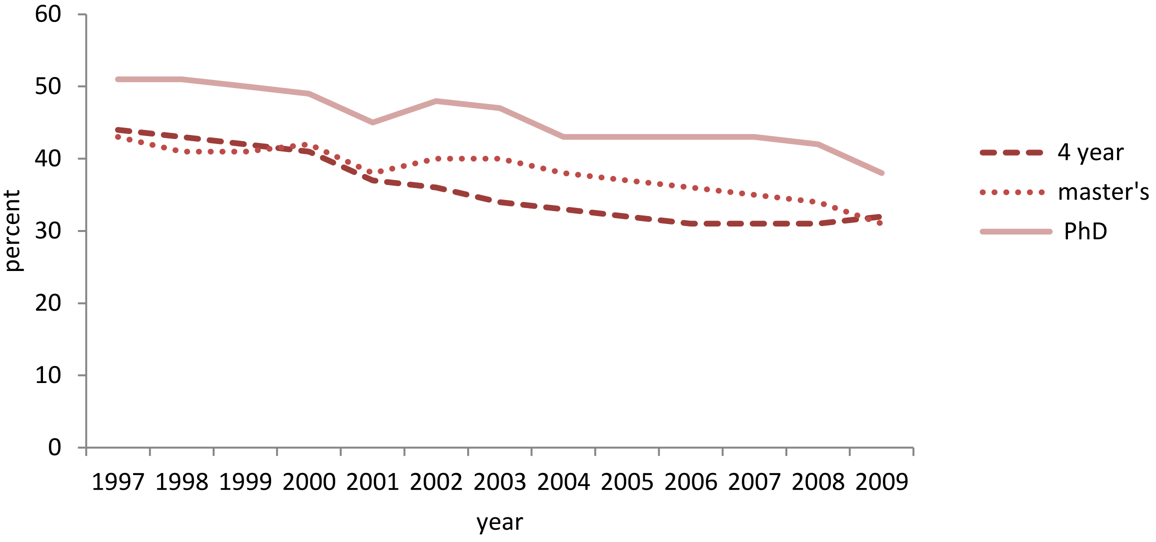
[1] This text on China relies heavily on Carnoy et al. (2013).

[2] The majority of higher education institutions are public rather than private. For the last decade, private universities have also been allowed to proliferate and offer four-year degrees, but they still absorb only about one-fifth of all four-year undergraduate students (NBS 2010a). They also only account for less than a third of higher education institutions.

(30 percent of total master's degree students). More than 40 percent of Chinese PhD students are studying in an engineering field. Given the huge number of university students in China and the fact that few students drop out of university or fail, the number of engineering graduates produced by the system is also large. In 2009, China's universities produced more than 700,000 bachelor-level engineering graduates. Roughly 8 to 10 percent of the new undergraduates entering engineering programs matriculated at China's top 100 elite universities.[3] Chinese universities also produced approximately 10,000 engineering PhDs, more than any other country in the world (NBS 2010a, 2010b).

Figure 22: Students in Engineering among All University Students, by Degree Level, China, 1997–2009



Source: NBS various.

The classification of specific majors within engineering is still fairly narrow in comparison with the classification system used in the United States. (China's classification is a remnant of the old Soviet system). China's Ministry of Education classifies engineering majors into 205 categories at the undergraduate level. The three areas with the highest enrollments are electronics and information engineering, mechanical engineering, and civil engineering and architecture, which, together, account for slightly over 70 percent of all engineering enrollments in higher education institutions. Currently, there are reportedly 24,392 engineering programs at the undergraduate level (MOE 2011).

Funding

China introduced cost-sharing, that is, tuition fees, in the 1990s. By 2009, 49 percent of higher education funding came from direct government contributions, while 33 percent came from student fees. Furthermore, policy makers could influence the amount of funding available to particular specializations by (1) regulating tuition prices according to colleges and majors to some degree, (2) providing earmarked or categorical grants for particular projects in engineering

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[3] The calculations are based on administrative data on all students that entered four-year colleges in 30 (out of 31) provinces in 2009.

education and research, and (3) providing different allocations per student for different major specializations (such as engineering). There is little systematic information available on the first two mechanisms. Regarding the last, however, it is known that, after 2008, the government introduced a new system of weighting allocations per student by major specialization (and not by type of institution, as had been done previously). Specifically, as of 2008, engineering majors received a weight of 1.33 compared to the weight of 1.00 for students in humanities-type majors, 1.25 for economics and education-related majors, and 2.50 for medical majors (MOF and MOE 2008).

Quality assurance and accreditations

In recent years, the China Association for Science and Technology, the Ministry of Education, the Ministry of Housing and Urban-Rural Development, and the Chinese Academy of Engineering led a pilot engineering accreditation program. The program established a national expert committee, comprised of senior scholars and engineers, for the programmatic accreditation of engineering education. The committee drafted a set of accreditation criteria, in addition to guidelines for participating institutions and programs. The four disciplines chosen for the initial round of piloting were electrical engineering and automation, mechanical engineering and automation, chemical engineering, and technology and computer engineering.[4] This pilot accreditation shifted the focus of the evaluation of higher education engineering programs from self-evaluation to outside evaluation, emphasizing teaching practices and student learning outcomes as indicators of quality (Bi 2009). Since then, there has been increased international cooperation (most notably with Hong Kong SAR, China; Japan; and Korea) and an expansion in the number of disciplines embraced in the pilot program, including mechanical engineering, electrical engineering, and hydraulic engineering. However, it appears that much of the work in programmatic accreditation is still in the conceptual stage. The national expert committee continues to carry out research on evaluation, accreditation, and registration with the hope of offering specific policy recommendations that will advance the process of China's adhesion to the Washington Accord.

Issues and challenges

China still faces many challenges in guaranteeing the quality of engineering education, especially in nonelite institutions at the undergraduate level and at the graduate level in general. One issue is that the quality of courses, curricula, and instruction may be substandard in the less-selective nonelite institutions. While the Ministry of Education sets the total number of credit hours per major and designates certain courses that should be studied, course specifics, including the number of credit hours devoted to particular types of courses, the choice of curricular materials, and instructional practices, are left to the discretion of individual institutions and faculty.

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[4] See "Reform of China's Engineer System and China's Engineering Program Accreditation," China Association for Science and Technology, Beijing, http://english.cast.org.cn/n1181872/n1182065/n1182088/46506.html. China has also had experience with accreditation in civil engineering since the 1990s. Specifically, in 1994, the National Board of Civil Engineering was formed and, in 1995 and 1997, granted accreditation to civil engineering programs in 18 higher education institutions (Bi 2009).

Another issue is that students still seem to lack practical (research and internship) experience, as well as exposure to certain soft skills that are emphasized in the U.S. model of engineering education. For example, only a small share of engineering students appear to be participating in faculty research projects, engaging in meaningful internships, or taking leadership or interdisciplinary courses. Furthermore, four-year students are generally known to complete a rather concentrated, classroom-oriented course schedule in the first three years, but then spend much of their last year searching for jobs.

Further impacting the quality of engineering graduates is the fact that students in China (especially in the less-selective institutions) have few incentives to perform well in college because they are, essentially, guaranteed a diploma after the designated period of study. This raises questions about the relative value added in Chinese engineering programs. If Chinese students are guaranteed graduation, this may reduce student learning, particularly at nonelite institutions. More specifically, while students at the best Chinese universities and at the more-selective second-tier institutions may be motivated to study seriously in college to enter graduate school at home or abroad, the majority of students in the less-selective second-tier universities and those in third-tier universities may have much less incentive to perform well in their studies.

Finally, it is an outstanding question whether Chinese engineering graduates meet employer demands. According to somewhat dated reports from the mid-2000s, employers find that the overall quality of Chinese engineering graduates is rather low. Specific problems include a mismatch between the skills possessed by graduates and those required by companies, a lack of practical engineering experience, an absence of creativity and risk-taking behavior, and substandard English and communication skills (Farrell and Grant 2005; Cha 2007; Wadhwa et al. 2007; Simon and Cao 2009). At the same time, however, the employment rate among recent engineering graduates is fairly high (around 85–90 percent), as is the rate of returns to college, especially in comparison with graduates in other majors (Carnoy et al. 2013).

The future of engineering education

In their plans to improve the quality of higher education, Chinese policy makers have not specifically targeted engineering education.[5] Rather, the targets for improving the quality of engineering education are encompassed within the broader goal of improving higher education in general. This includes providing more resources for postgraduate students and improving faculty skills and qualifications.

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[5] For example, see “National Medium and Long-Term Plan for Educational Reform and Development, 2010–2020,” Ministry of Education, Beijing, http://www.moe.edu.cn/publicfiles/business/htmlfiles/moe/s3501/index.html.

Appendix B. The Top Five Disciplines in Engineering

Table 6: The Top Five Disciplines among Undergraduates

a. Japan, Russian Federation, United Kingdom, and United States

total students

Rank	United States		United Kingdom		Japan		Russian Federation	
	Discipline	Students	Discipline	Students	Discipline	Students	Discipline	Students
1	Mechanical engineering	108,623	Mechanical engineering	19,765	Telecommunications engineering	123,049	Architecture and building	159,787
2	Civil engineering	56,605	Electronic and electrical engineering	18,970	Other	81,497	Transport	129,941
3	Electrical engineering	49,871	Civil engineering	16,605	Mechanical engineering	71,670	Computer science	103,911
4	Other engineering discipline	46,927	General engineering	11,255	Civil engineering and construction	58,104	Energy, power machine building, and electrical engineering	96,820
5	Computer science, including English	42,277	Aerospace engineering	6,385	Applied chemistry	36,314	Metallurgy, mechanical engineering, and material processing	85,162

b. China, Brazil, and India

total students

Rank	China		Brazil		India	
	Discipline	Students	Discipline	Students	Discipline	Students
1	Electronics and information	3,297,872	Civil engineering	99,521	Engineering and technology	1,001,064
2	Mechanical engineering	1,380,919	Production engineering	87,208	Pharmacy	52,180
3	Civil engineering and architecture	894,490	Electrical engineering	59,040	Hotel management and catering	3,454
4	Transportation	455,911	Mechanical engineering	55,172	Architecture and town planning	3,092
5	Light industry, textiles, and food	350,115	Environmental engineering	31,485	Management	1,361

Table 7: The Top Five Disciplines among Graduate Students

a. Japan, Russian Federation, United Kingdom, and United States

total students

Rank	United States		United Kingdom		Japan		Russian Federation	
	Discipline	Students	Discipline	Students	Discipline	Students	Discipline	Students
1	Mechanical engineering	22,311	Electronic and electrical engineering	10,455	Telecommunications engineering	22,219	Architecture and building	99,692
2	Electrical engineering	21,616	Civil engineering	7,365	Mechanical engineering	10,606	Transport	81,470
3	Petroleum engineering	20,507	General engineering	6,360	Civil engineering and construction	9,018	Energy, power machine building, and electrical engineering	61,235
4	Computer science, including English	20,480	Mechanical engineering	5,230	Applied chemistry	6,757	Metallurgy, mechanical engineering, and material processing	57,813
5	Electrical computer engineering	15,451	Chemical, process and energy engineering	3,505	Management engineering	1,131	Computer science	57,612

b. China, Brazil, and India

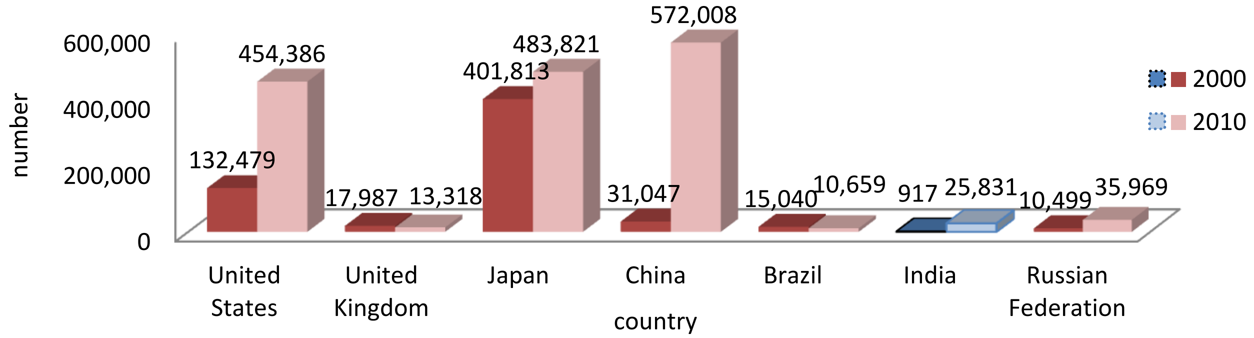
total students

Rank	*China*		*Brazil*		*India*	
	Discipline	*Students*	*Discipline*	*Students*	*Discipline*	*Students*
1	n.a.	n.a.	Electrical engineering	5,746	n.a.	n.a.
2	n.a.	n.a.	Civil engineering	4,467	n.a.	n.a.
3	n.a.	n.a.	Mechanical engineering	3,965	n.a.	n.a.
4	n.a.	n.a.	Chemical engineering	2,943	n.a.	n.a.
5	n.a.	n.a.	Production engineering	2,865	n.a.	n.a.

Note: — = not available.

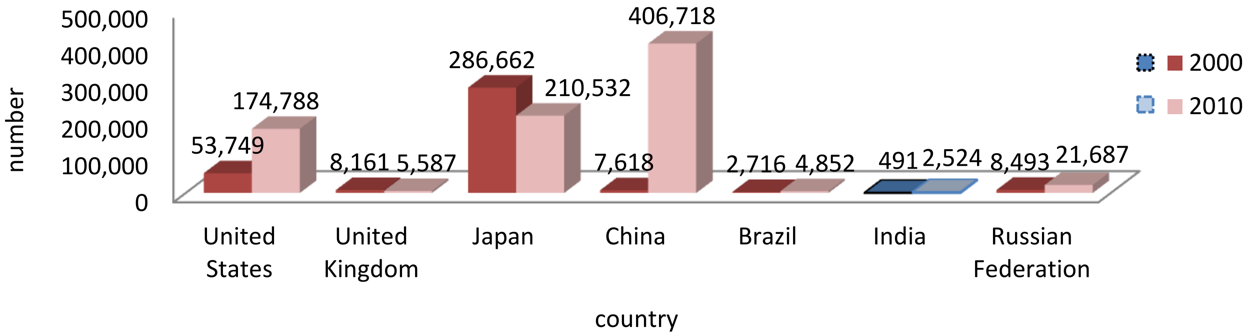
Appendix C. Research and Commercialization Outputs: Corporate Patents

Figure 23: Corporate Patents, Total



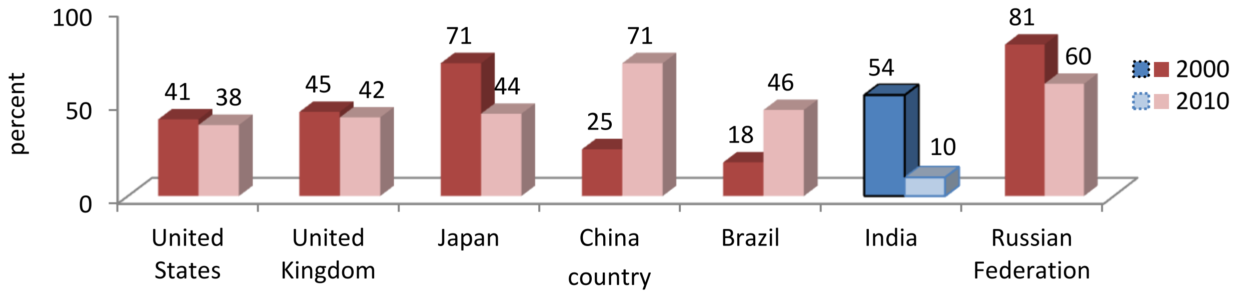
Source: Derwent World Patents Index (database), Thomson Reuters, Philadelphia, http://thomsonreuters.com/products_services/legal/legal_products/a-z/derwent_world_patents_index/.

Figure 24: The Volume of Inventions (Basic Patents) among Corporate Patents



Source: Derwent World Patents Index (database), Thomson Reuters, Philadelphia, http://thomsonreuters.com/products_services/legal/legal_products/a-z/derwent_world_patents_index/.

Figure 25: Ratio of Basic Patents to Total Patents, Corporations



Source: Derwent World Patents Index (database), Thomson Reuters, Philadelphia, http://thomsonreuters.com/products_services/legal/legal_products/a-z/derwent_world_patents_index/.

Appendix D. Indicators: Data Collection Status

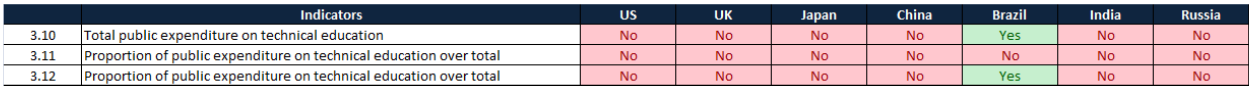
Table 8: Students, Faculty, and Institutions

Item Number	Indicators		US	UK	Japan	China	Brazil	India	Russia
1.01	Undergraduate	Number of Male Student	Yes	Yes	Yes	Yes	Yes	Yes	Yes
		Number of Female Student	Yes	Yes	Yes		Yes		Yes
1.02	Master	Number of Male Student	Yes	Yes	Yes	Yes	Yes		Yes
		Number of Female Student	Yes	Yes	Yes		Yes		Yes
1.03	PhD	Number of Male Student	Yes	Yes	Yes	Yes	Yes		Yes
		Number of Female Student	Yes	Yes	Yes		Yes		Yes
1.04	Undergraduate	Number of Students by discipline (civil, etc)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1.05	Post-gradaute	Number of Students by discipline	Yes	Yes	Yes	No	Yes	No	Yes
1.06	Undergraduate	Number of sanctioned seats	No	No	No	N/A	Yes	No	Yes
1.07	Post-gradaute	Number of sanctioned seats	No	No	No	N/A	Yes	No	Yes
1.08	Public	Number of students	Yes	Yes	Yes	Yes	Yes	No	Yes
1.09	Private	Number of students	Yes	N/A	Yes	Yes	Yes	No	Yes
1.10	Public	Number of Male Faculty	Yes	Yes	Yes	Yes	Yes	No	No
		Number of Female Faculty		Yes	Yes			No	No
1.11	Private	Number of Male Faculty		N/A	Yes		Yes	No	No
		Number of Female Faculty		N/A	Yes			No	No
1.12	Public	Qualification of Faculty (a) Percentage with PhD degree	No	Yes	Yes	No	Yes	No	No
1.13		Qualification of Faculty (b) Percentage with Master degree	No	Yes	Yes	No	Yes	No	No
1.14	Private	Qualification of Faculty (a) Percentage with PhD degree	No	N/A	Yes	No	Yes	No	No
1.15		Qualification of Faculty (b) Percentage with Master degree	No	N/A	Yes	No	Yes	No	No
1.16	All	Qualification of Faculty (a) Percentage with PhD degree	Yes	Yes	Yes	No	Yes	Yes	No
1.17		Qualification of Faculty (b) Percentage with Master degree	Yes	Yes	Yes	No	Yes	Yes	No
1.18	Percentage of faculty positions filled with regular staff		Yes	Yes	Yes	No	Yes	No	Yes
1.19	Ratio of professors, Associate Professors, Assistant Professors		Yes	Yes	Yes	Yes	Yes	No	Yes
1.2	Ratio of Permanent, Contract, Part-time academic staff		Yes	Yes	Yes	No	Yes	No	Yes
1.21	Public	Number of Engg education institutions at higher education level	Yes	N/A	No	Yes	Yes	Yes	Yes
1.22	Private	Number of Engg education institutions at higher education level		N/A	No		Yes	Yes	Yes
1.23	Public	Number of higher education instituions offering B.A or above degree in engg education	Yes	Yes	Yes	Yes	Yes	No	Yes
1.24	Private	Number of higher education instituions offering B.A or above degree in engg education	Yes	No	Yes		Yes	No	Yes
1.25	Public	Number of Engg education institutions with ACADEMIC AUTONOMY	No	Yes	No	N/A	Yes	Yes	Yes
1.26	Private	Number of Engg education institutions with ACADEMIC AUTONOMY	No	N/A	No	N/A	Yes	Yes	No

Table 9: Education Outputs

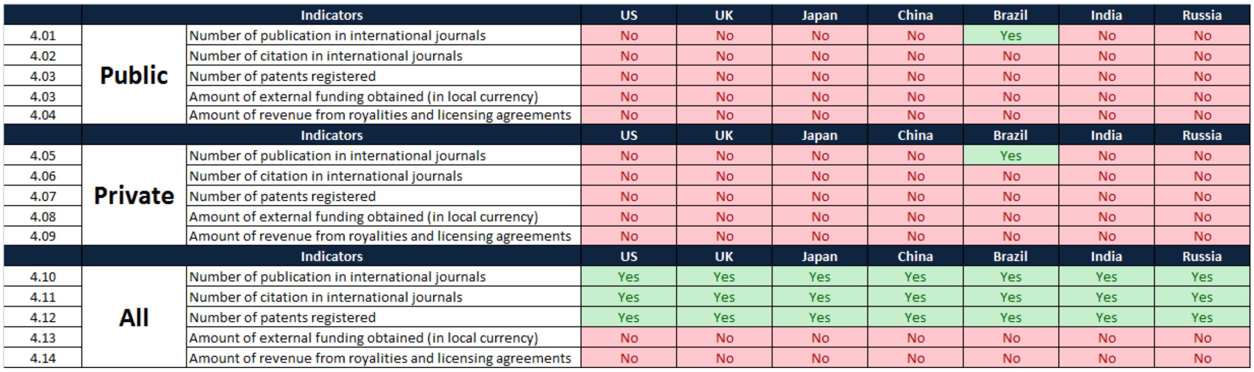
	Indicators		US	UK	Japan	China	Brazil	India	Russia
2.01	**Public**	UG Number of Graduates	Yes	Yes	Yes	Yes	No	No	No
2.02		Master Number of Graduates	Yes	Yes	Yes	Yes	No	No	No
2.03		PhD Number of Graduates	Yes	Yes	Yes	Yes	No	No	Yes
2.04		Percentage of programmes accredited	Yes	No	No	N/A	Yes	No	Yes
2.05		Repetition rate	No	No	No	Yes	No	No	No
2.06		Graduation rates	No	No	No	Yes	No	No	No
2.07		Employment Rates	No	Yes	No	No	Yes	No	No
	Indicators		US	UK	Japan	China	Brazil	India	Russia
2.08	**Private**	UG Number of Graduates	Yes	N/A	Yes	Yes	No	No	No
2.09		Master Number of Graduates	Yes	N/A	Yes	Yes	No	No	No
2.10		PhD Number of Graduates	Yes	N/A	Yes	Yes	No	No	Yes
2.11		Percentage of programmes accredited	Yes	N/A	No	Yes	Yes	No	Yes
2.12		Repetition rate	No	N/A	No	Yes	No	No	No
2.13		Graduation rates	No	N/A	No	Yes	No	No	No
2.14		Employment Rates	No	N/A	No	No	Yes	No	No
	Indicators		US	UK	Japan	China	Brazil	India	Russia
2.15	**All**	UG Number of Graduates	Yes	Yes	Yes	Yes	Yes	No	No
2.16		Master Number of Graduates	Yes	Yes	Yes	Yes	Yes	No	No
2.17		PhD Number of Graduates	Yes	Yes	Yes	Yes	Yes	No	Yes
2.18		Percentage of programmes accredited	Yes	No	No	N/A	Yes	No	Yes
2.19		Repetition rate	No	No	No	Yes	No	No	No
2.20		Graduation rates	No	No	Yes	Yes	No	No	No
2.21		Employment Rates	No	Yes	Yes	Yes	Yes	No	No

Table 10: Education Expenditure



	Indicators	US	UK	Japan	China	Brazil	India	Russia
3.10	Total public expenditure on technical education	No	No	No	No	Yes	No	No
3.11	Proportion of public expenditure on technical education over total	No	No	No	No	No	No	No
3.12	Proportion of public expenditure on technical education over total	No	No	No	No	Yes	No	No

Table 11: Research and Commercialization Output



	Indicators		US	UK	Japan	China	Brazil	India	Russia
4.01	**Public**	Number of publication in international journals	No	No	No	No	Yes	No	No
4.02		Number of citation in international journals	No	No	No	No	No	No	No
4.03		Number of patents registered	No	No	No	No	No	No	No
4.03		Amount of external funding obtained (in local currency)	No	No	No	No	No	No	No
4.04		Amount of revenue from royalities and licensing agreements	No	No	No	No	No	No	No
	Indicators		US	UK	Japan	China	Brazil	India	Russia
4.05	**Private**	Number of publication in international journals	No	No	No	No	Yes	No	No
4.06		Number of citation in international journals	No	No	No	No	No	No	No
4.07		Number of patents registered	No	No	No	No	No	No	No
4.08		Amount of external funding obtained (in local currency)	No	No	No	No	No	No	No
4.09		Amount of revenue from royalities and licensing agreements	No	No	No	No	No	No	No
	Indicators		US	UK	Japan	China	Brazil	India	Russia
4.10	**All**	Number of publication in international journals	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4.11		Number of citation in international journals	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4.12		Number of patents registered	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4.13		Amount of external funding obtained (in local currency)	No	No	No	No	No	No	No
4.14		Amount of revenue from royalities and licensing agreements	No	No	No	No	No	No	No

Appendix E. Data Sources and Data Year

Institutions

This study covers engineering education in higher education institutions, which are defined as public and private institutions (either university or college, excluding polytechnics) that are providing engineering courses as a part of academic disciplines at university or that are specializing in engineering courses (engineering education institution) (Table 12). The institutions on which the study focuses offer bachelor's degrees or above, which is equivalent to ISCED 2011, levels 6, 7, and 8 (ISCED 1997, levels 5A and 6).[1] Both full- and part-time courses are included.

Table 12: Data on Institutions

Country	*Data source*	*Data year*	*Note*
United States	ASEE	2011	
United Kingdom	HESA	2010–11	
Japan	MEXT	2011	
China	Ministry of Education	2009	
Brazil	National Institute for Educational Studies and Research	2010	
India	AICTE	2011–12	Approved technical institutions in engineering are included. Public/private distinction is obtained from AICTE Approval Process Handbook: 2012-13
Russian Federation	National Accreditation Agency of the Russian Federation	2010	Branches of institutions are not included.

Students

The study covers both full-time and part-time students enrolled in engineering programs in universities or colleges that offer bachelor's degrees or above. Part-time students and full-time students are counted equally, and no special weight is assigned to them. Students taking part in open or distance learning are not covered. Depending on the country, there are differences in the definitions of engineering and levels of education, in school systems, and in the availability of stratified data (Table 13). Thus, comparability is not perfect. For example, in the United Kingdom, PhDs are not the only type of doctorate available (indeed, other types are more common). In China, the share of students enrolled in public and private institutions is estimated in the study. In India, only the total number of students enrolled in the engineering or technology discipline is available; therefore, the number of students enrolled in undergraduate, master's, and PhD programs is estimated. In Russia, in addition to bachelor's, master's, and PhD programs, there is also a specialist program, which lasts five years and is similar to the level of a master's program. Because of the large number of students enrolled in the specialist program, the number of students in Russia is large. The program consists of a basic block of courses that lasts three years and a specialty block that lasts two years. For the purpose of comparing the numbers of undergraduate students and postgraduate students across countries, the basic block of courses

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[1] See UNESCO (1997) for ISCED 1997 and UNESCO (2012) for ISCED 2011.

(the first three years) is counted as a bachelor's stage, and the specialty block (the later courses) is counted as a master's stage in this study.

Table 13: Data on Students

Country	*Data source*	*Data year*	*Scope of the term engineering*	*Note*
United States	ASEE	2011	Students enrolled in all engineering and all engineering technology[a]	ASEE data are used for all engineering disciplines for all degrees and all engineering technology disciplines for the master's degree. National Science Foundation data are used for the engineering technology discipline for the bachelor's degree. They include more engineering technology schools relative to the ASEE data, but they are limited to the bachelor's degree. Thus, the study uses these data only for the bachelor's degree.
	National Science Foundation	2009		
United Kingdom	HESA	2010–11	Students enrolled in software engineering under the computer science discipline and the engineering and technology discipline	Undergraduate: students in first degree programs Master's: students in other higher degree programs PhD: students in doctorate programs, although they are not exclusively PhD students; this number is the closest approximation produced by HESA
Japan	MEXT	2011	Students enrolled in the engineering discipline	
China	*China Statistical Yearbook 2010* (NBS 2010a)	2009	Students enrolled in four-year bachelor engineering programs	The share of students enrolled in public and private institutions is estimated by utilizing 21.6 percent as the share of students in private institutions because this is the share of new bachelor's entrants in 2009 in private higher education institutions.
Brazil	National Institute for Educational Studies and Research (undergraduate); CAPES (master's and PhD)	2010		Men and women students are calculated by multiplying the total number of students by the share of men and women students indicated in the 2007 census of the National Institute for Educational Studies and Research (79.3 percent men and 20.7 percent women) for undergraduates and in the data of the Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul for master's and PhD students. Data of the National Institute for Educational Studies and Research provide the share of public and private institutions we used to calculate the students enrolled in public and private institutions.
India	UGC (2011); AICTE data	2009–10	Students enrolled in the engineering-technology discipline	The provisional number for 2009–10 in UGC (2011) is used for the total number of students. AICTE (2011) data on the intake approved for 2011–12 in engineering and technology are used to calculate the share of students at each level of academic programs. Undergraduate is listed as undergraduate; master's is listed as postgraduate; and PhD is listed as Doctor of Philosophy in the AICTE data. Public/private distinction is calculated from the AICTE data.
Russian Federation	Federal State Statistics Service of the Russian Federation	2010	Students enrolled in the engineering discipline	Undergraduate includes ISCED, level 5A (bachelor's and the basic block of courses (the first three years only); master's includes ISCED, level 5A (the specialty block of courses (the last two years) and master's programs only; PhD includes candidates in science programs.[b]

a. Engineering students take more mathematics courses relative to engineering technology students and also study a higher level of mathematics. Engineering programs focus on theory, whereas engineering technology programs focus on application. After graduation, engineering graduates are called engineers and spend their time planning rather than implementing. Engineering degrees most often terminate at the bachelor's degree, considered the professional degree or the degree level required that allows students to become licensed engineers. However, students may continue their studies to graduate with a master's degree or a PhD in engineering. Engineering technology degrees mostly terminate at the associate's degree or bachelor's degree and, in some cases, the master's degree.

b. ISCED 1997, level 5A is a subcategory of ISCED 1997, level 5, the first stage of tertiary education. It is largely theoretically based and is intended to provide sufficient qualifications for gaining entry into advanced research programs and professions with high skill requirements (OECD 2004).

Faculty

Full-time and part-time faculty who are teaching engineering courses at institutions offering bachelor's degrees and above are covered in our study. Both teaching and research faculty are included; however, it has been difficult to obtain disaggregated data on men and women and on faculty teaching at public or private institutions. Thus, we have made only a limited comparison (Table 14). While almost all the countries produce data on faculty, our data on India and Russia are estimates. In India, no official data are available on engineering faculty. Therefore, we have made estimates by using the student-faculty ratio in general higher education, which is 1 to 24. We have used this ratio to estimate the number of engineering faculty as well. Given that it is considered more difficult to recruit engineering faculty than faculty in general higher education, our estimate may be conservative. In the United Kingdom, the scope of faculty is defined in detail, and we include academic staff whose professional markers are either professor or not a professor. Professor indicates that the contract confers the title of professor to the holder, while not a professor is an academic staff member who is responsible for planning, directing, and undertaking academic teaching and research within higher education institutions. These academic staff are further categorized according to academic functions of employment, among which we have included those who are categorized as teaching only, research only, teaching and research, and not teaching or research. An example of a staff member who is not doing teaching or research might be a vice-chancellor. Both open-ended–permanent and fixed-term contract faculty are included.

Table 14: Data on Faculty

Country	*Data source*	*Data year*	*Note*
United States	ASEE	2011	Tenure track, teaching (nontenure), and research (nontenure) faculty in all U.S. engineering schools, including in Puerto Rico, are included.
United Kingdom	HESA	2010-11	Academic staff whose professional markers are either professor or not a professor are included.
Japan	MEXT	2010	Teachers in disciplines including engineering in their names are included.
China	Official government statistics	2009	
Brazil	National Institute for Educational Studies and Research	2010	The share of regular (full-time) and nonregular (part-time) faculty is calculated from the 2007 census of the National Institute for Educational Studies and Research.
India	MHRD (2011b)	2011	No official data are available on engineering faculty. Therefore, the student-faculty ratio (1:24) in general higher education is used as a proxy.
Russian Federation	Federal State Statistics Service of the Russian Federation	2010	The number of faculty is estimated by dividing the total number of faculty in secondary vocational and higher education institutions by the share of students who are in engineering programs in public and private educational institutions within the overall number of students. Faculty with specialist diplomas are also included as faculty with master's degrees because the specialist diploma is broadly equivalent to a master's degree.

Graduates

The data on graduates covers those students who graduated in the relative year, including graduates who had transferred from another discipline to an engineering discipline and graduates who took more or fewer years to complete the course than the number of years expected for completion (Table 15). The data on graduates are available in each country. However, in India, data are only available for 2005–06, and these data are not comparable because of the substantial expansion of the engineering system in India that is discussed in section 2. Thus, we have not used this number.

Table 15: Data on Graduates and Degrees

Country	*Data source*	*Data year*
United States	ASEE, National Science Foundation (bachelor’s graduating with engineering technology degrees: NSB 2010)	2011, 2009
United Kingdom	HESA	2010–11
Japan	MEXT	2011
China	Ministry of Education	2010
Brazil	National Institute for Educational Studies and Research (undergraduates); CAPES (postgraduates)	2010
India	Not available	
Russian Federation	Federal State Statistics Service and ongoing observations	2010

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