# Issues in Human Resources in Science and Engineering: India

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## Introduction

India continues to produce a substantial quantity of science and engineering (S&E) personnel through its educational system and through higher education overseas. Over the last 3 decades, there has been a steady increase in student enrollment, adding up to nearly 6.5 million by 1996. However, enrollment in basic sciences has dropped to 19.6 percent (from 30 percent) of the total over this period, and there has not been a significant increase in enrollment in engineering and technology (which account for about 5 percent of the total).

In this paper, the focus is on the trends in the generation of these human resources in India and how certain important economic changes may have an impact on the career paths and opportunities for these personnel.

Current data on S&E personnel in India are limited, with the most recent sources being *Research and Development Statistics* (DST 1996) and the 1998 *Science & Engineering Indicators* report (NSB 1998) of the National Science Foundation (NSF). Nevertheless, broad implications may be drawn based on these data and analyses of current important economic circumstances. This discussion paper is based to a large extent on qualitative assessments of trends in S&E graduate education and is meant to serve primarily as a basis for further discussion and identification of areas for future research and data collection.

S&E graduate education needs to be viewed in the context of the major issues that face Indian S&E personnel and national policymakers: the impact of the dynamic growth of the information technology industry worldwide and its effects on demands for skills, the economic downturn in Asian economies (even though at this point India has not been as adversely affected as other nations in the region), and what NSF refers to as the "circulation" of human resources in S&E. Also important is the growing concern over the need for enhancing technology-based economic development and the consequent demand for enhanced involvement of S&E personnel in the productive sector.

## Generation of S&E Personnel in India

In an overall sense, India continues to produce S&E personnel at a steady rate, and currently has a stock of over 6.3 million (Rao 1998). Of these, however, only about 150,000 are engaged in research and development (R&D), mostly in governmental laboratories. The rest are either overseas or in nontechnical careers; some are in industry. Table 1 shows the growth in doctorate recipients from India (in the United States) over the period 1985-96.

As can be seen, the proportion of total Ph.D.s awarded in S&E areas has remained more or less constant, except in more recent years when it has increased somewhat. The median age for a Ph.D. has stayed somewhat stable as well, at around 29 years.

Within S&E, allocation across fields has changed. The greatest increase has been in the computer and information sciences, which accounted for 3.9 percent of total S&E doctorates in 1985 and 9.1 percent in 1996, reflecting the rapid growth in the information technologies (IT) industry and the attractiveness of this field from a career standpoint. It is noteworthy that many of the Indians in the software and hardware industries in India and overseas hold advanced degrees.

Of these, most had clear plans to stay in the United States after receipt of their Ph.D. According to the DST report, 1,082 of the 1,482 recipients in 1996 had firm plans

**Table 1. Number of Ph.D.s from India by year of award, 1985-96**

| Year | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total | 541 | 579 | 602 | 647 | 679 | 881 | 924 | 1,072 | 1,139 | 1,289 | 1,426 | 1,481 |
| S&E (percent) | 84 | 81 | 83 | 80 | 78 | 80 | 81 | 80 | 81 | 82 | 84 | 84 |

**SOURCE:** Government of India, Ministry of Science and Technology, Department of Science and Technology, *Research and Development Statistics,* New Delhi, India, September 1996.

to locate in the United States after receiving their Ph.D.; 456 of these had definite employment plans. Most of the employers (79.2 percent) were in industry/business, and 15.8 were educational institutions. In contrast, in 1985, 47.4 percent of the employers were in industry/business and 44.5 percent were educational institutions.

To bring greater depth to this scenario, data are required on the numbers of advanced degree-holders of Indian origin who have returned to India and the location of their employment there. Typically, even though Indian Ph.D.s have tended to prefer to stay in the United States, the rapid growth in certain sectors of the Indian economy and greater overall mobility should suggest an increase in this recirculation of skills.

There is another side to the coin, however. Even though there are data that indicate that "brain circulation" is occurring for some countries such as Taiwan and South Korea, India and China still experience more "brain drain" than not. This is perhaps understood by the fairly high level of S&E personnel in India actively seeking employment. According to DST, 676,099 science graduates and 100,249 science postgraduates, as well as 152,015 engineering graduates and postgraduates combined, were on the active registers of employment exchanges in 1993. More current data are not available.

Given that economic conditions may have made it favorable for S&E personnel to return to India if they entered specific industry/business areas but that overall employment prospects for them do not seem to have improved, research is needed to determine what specific trends are emerging as a result.

This is particularly important when viewed from a national economic development perspective. Ideally, countries like India need to harness their S&E personnel and capabilities to accelerate the development process and further the development of national science and technology infrastructure, research, and training. A major channel through which this could occur is the national laboratory system (e.g., the Council of Scientific and Industrial Research—CSIR) and national teaching institutes such as the Indian Institutes of Technology (IITs). There has been considerable criticism of the extent to which mechanisms have actually made contributions to the productive sphere; it is only recently, for example, that the CSIR system has been asked to focus its energies on such efforts. This has been accompanied in many cases by budget cutbacks, which have limited the ability of national labs to offer attractive salaries and career prospects to new graduates. The upshot is that the private sector, and in particular the information technology area, is becoming a major career choice for such graduates.

This in turn is having an impact on the supply of future teachers (Rao 1998, p. 29):

> In the field of postgraduate education and research in engineering and technology the following trends are worrisome. (1) The average turnout of Master's Degree holders in engineering technology is only around 5,000 per year and this is against the capacity of more than 15,000. (2) The loss of engineering graduates to software industry is taking place on a large scale with consequences to postgraduate programmes. On account of these negative developments there is an acute shortage of teachers with postgraduate qualifications in engineering and technology. The situation is becoming one of concern as expansion in engineering education will have to go hand in hand with economic growth. (3) The number of doctorates in engineering and technology being produced annually now is only about 400 and 90 percent of them come from only a dozen institutions.

Indeed, as table 2 shows, the number of doctorates in engineering has dropped considerably over the period 1982-94.

**Table 2. Doctorate degrees awarded by field**

| Faculty | 1982–83 | 1990–91 | 1993-94 |
|---|---|---|---|
| Total | 6,948 | 8,383 | 9,369 |
| Engineering/tech | 511 | 629 | 348 |

**SOURCE:** Government of India, Ministry of Science and Technology, Department of Science and Technology, *Research and Development Statistics,* New Delhi, India, September 1996.

In science, however, the number of doctorates has increased from 2,892 in 1982-83 to 3,505 in 1993-94. The overall total number of doctorates has also increased, rising from 6,948 in 1982-83 to 9,369 in 1993-94.

DST has compiled estimates of the total stock of engineering degree-holders by discipline; these are summarized in table 3.

| Table 3. Engineering degree-holders by field | | | | |
|---|---|---|---|---|
| Discipline/Year | 1986 | 1990 | 1995 | 2000 |
| Total...................... | 390,830 | 492,180 | 660,660 | 848,660 |
| Civil................... | 94,540 | 11,940 | 153,160 | 186,830 |
| Mechanical........ | 108,400 | 131,200 | 164,220 | 197,980 |
| Electrical........... | 76,390 | 87,030 | 106,220 | 125,870 |
| Chemical........... | 23,660 | 27,510 | 32,300 | 37,700 |
| Telecom............ | 25,520 | 41,830 | 67,290 | 96,260 |
| Metallurgy......... | 11,960 | 13,120 | 14,880 | 16,780 |
| Automobile........ | 730 | 1,140 | 2,720 | 5,140 |
| Aeronautical...... | 1,360 | 1,530 | 1,760 | 1,950 |
| Other................. | 20,410 | 32,440 | 66,930 | 110,350 |

**SOURCE:** Government of India, Ministry of Science and Technology, Department of Science and Technology, *Research and Development Statistics,* New Delhi, India, September 1996.

The specific field of computer software and hardware is not detailed separately but is probably included within telecommunications, electrical engineering, and other.

It is perhaps worth comparing these figures with the numbers of first university degrees in S&E in India over the period 1985-95 (table 4).

| Table 4. First university degrees in S&E in India, 1985-95 | | | |
|---|---|---|---|
| Field | 1985 | 1990 | 1995 |
| All univ. degrees............ | 646,748 | 750,000 | 750,000 |
| Engineering............... | 21,088 | 29,000 | 29,000 |
| Math. & comp. sci...... | NA | NA | NA |

**SOURCE:** National Science Board, *Science & Engineering Indicators - 1998,* NSB-98-1 Arlington, VA, 1998.

Clearly, these is a general lack of available data on graduates in computer sciences (and mathematics); this is an important area in which further and more refined data collection is needed in order to better understand the changing composition of S&E degrees.

## S&E and Productivity

One of the major purposes of enhancing the quality, quantity, and proper deployment of S&E is economic development and the strengthening of the economy. Indian national science and technology (S&T) policy has always been based on this need as a central focus (along with an emphasis on self-reliance). Since independence, the generation of highly qualified scientists and engineers (and the establishment of premier educational institutions such as the IITs) have been driven by this objective. However, accomplishments in terms of concrete and positive contributions to productivity by S&T have been questionable, and one of the "negative" effects of an imbalance between the supply of personnel and the economy's absorptive capacity has been brain drain.

Today, the discussion has turned from brain drain to brain circulation, which may apply to some Asian countries more than others. Brain circulation appears to be occurring in some countries (but may change with the recent Asian economic crises). This takes place in the form of graduates returning to jobs back home, networking with colleagues in their countries of origin, and thereby creating more of a dynamic two-way flow of talents and skills between the United States and the home country.

Of paramount importance, however, is to investigate to what extent this type of circulation actually contributes to home countries' scientific and technological infrastructure (broadly defined to include research, training, policy, transfer of knowledge, etc.) and hence, in turn enhance the economic development process.

For example, considering that India is primarily an agricultural country and is the number one producer of certain commodities such as jute, sugar, fruits, and vegetables, it is—in terms of productivity—on the low end of the spectrum (Rao 1998, p. 19) (table 5).

| Table 5. Indian agricultural productivity | | | | |
|---|---|---|---|---|
| Type of Plant | Production | | Yield | |
| | Annual (1000 T) | World Rank | Yield kg/ha | World Rank |
| Jute.................... | 1,260 | 1 | 1,465 | 10 |
| Fruits/veg........... | 100 | 1 | Variable | Below 10 |
| Raw sugar.......... | 13-14,000 | 1 | 10% | Below 5 |

**SOURCE:** P. Rama Rao. "Science and Technology in India: Retrospect and Prospect." Address to the 85th Annual Session, Osmania University, Hyderabad, India, January 3, 1998.

The potential contribution of technological know-how and skills is critical in improving productivity in agriculture, a mainstay of the economy. Yet the trend in doctoral degrees awarded in agriculture from Indian universities has declined in recent years. The trend in doctoral recipients in agricultural sciences from the United States shows a similar decline, but precise data are not available (table 6).

| Table 6. Doctoral degrees awarded in agriculture in India | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 |
| 712 | 688 | 703 | 715 | 715 | 611 | 572 | 572 |

**SOURCE:** Government of India, Ministry of Science and Technology, Department of Science and Technology, *Research and Development Statistics,* New Delhi, India, September 1996.

This is the type of trend that raises concerns for the long term. Regardless of the tremendous growth and advances in areas such as IT, and the admittedly positive implications of these for productivity improvements in all sectors of the economy, the need for basic technological capabilities that can continue to improve agricultural efficiencies is critical to the long-term economic development of the nation.

Moreover, technological capacities are required for the further processing of agricultural commodities into value-added products, the economic benefits of which are growing rapidly worldwide. Adding value to agricultural resources is a mainstay of economic development: moving up the "value chain" is central to the wealth creation process that underlies economic development. For this to occur, the country needs personnel with skills in appropriate areas—food processing, fermentation, packaging, chemical engineering, tissue culture, biotechnology, etc. With these skill sets properly harnessed, the Indian economy could build a value-added industrial base that generates wealth from its agricultural and natural resource base.

For example, there is a growing demand for high-quality flavors and extracts (essences) by the global food and beverage, aromatics, and perfume industries. Indian spices, botanicals, fruits, and vegetables are acknowledged to be very high in taste and flavor content even though yields may be low. Market demographics have been changing in recent years: there is a growing consumer demand for exotic tastes and more variety in flavors and aromatics. The growth of new markets, for example aromatherapy and organic foods, is another driver of demand.

To meet these new demands and enter these markets competitively, capabilities in new technologies that provide higher extract yields and higher efficiencies are required. These technological developments are occurring in various countries around the world (substantially in the United States), and it is essential that India develop S&E personnel with skills in these areas. Such skills must be built upon a solid foundation of training and research in the appropriate area of agricultural engineering.

An important consideration here is that technical skills by themselves may not be adequate. There has to be an appreciation of market trends (and opportunities) and incentives for S&E personnel to pursue them. The knowledge of market opportunities needs to be dealt with by appropriate modifications to the teaching/research program. Incentives for S&E personnel can only come from private industry and through national policies.

## Broader Economic Context of S&E Education

Rao (1998) makes a strong and crucial argument that the broader economic context within which scientific and engineering activities take place—including education—must be taken into consideration in all aspects of S&T policy. Of particular importance are the commercial aspects of technology. To fully capitalize on the competitive resources of the country, there is a need to focus S&T activities in such a way as to optimize the commercialization, in a competitive sense, of scientific and technological know-how.

In this regard, education in S&E must be based on a broader concept of knowledge than simply functional specialization. Of specific importance are the areas of finance, organization and management, and marketing. These are areas with which S&E personnel need to have a working familiarity. The base of such expertise, interestingly enough, may already be developing, with various government agencies involved in S&T in India becoming more involved with venture capital, technology commercialization, and market-driven approaches to S&T. The recently created Technology Development Board is one such example; its mission is to promote the commercial development of technology and mobilize the resources and inputs needed for this end.

This need is present in most sectors of the Indian economy—health, pharmaceuticals, chemicals, agriculture, telecommunications, transportation, energy, etc. The challenge for the future is to be able to identify, with some accuracy, which are the opportunity areas of the future and to develop educational programs to generate the skill sets that will be required. This is admittedly a major undertaking. Fortunately, in the United States and Europe, educational and research programs in the relevant areas already exist and can be taken advantage of by Indian students.

Another dimension of the global context is the very process of globalization itself. Corporations are becoming increasingly global in their character, and the economies of the world—as evidenced by recent economic events in Asia and Latin America—are becoming increasingly intertwined. As a result, one finds U.S. corporations with a global reach paying more attention to the recruitment of talent from the countries in which they operate and depending increasingly on skills available in these countries. This applies not only to the mainstream areas of S&E but also to the newly emerging ones, such as IT, as well. For example, nearly every major U.S. software company has established a development operation in India, with the intention of utilizing the vast and still relatively inexpensive technical resources available there. This has two effects: first, there is tremendous mobility in the IT field between the United States and India, and the number of Indians in this industry—for example, in Silicon Valley—has skyrocketed in the past decade. Second, the growth of the industry is drawing people away from other career paths in S&E, with the consequent implications for long-term economic development discussed earlier.

There is another trend that is gradually emerging that is of significance in educational terms. Indian engineering graduates, mainly from the IITs, are now being found in high-level positions in the financial sector. For example, an IIT graduate is now head of Citibank worldwide. Many of the senior staff in multilateral financial institutions, such as the International Finance Corporation and the World Bank, are Indian engineering graduates from the 1970s and 1980s. They in turn are becoming role models for future generations of engineering graduates.

In the past, for the most part, Indian students came to the United States to study S&T with a clear intention of staying in that field throughout their careers. A subtle but important change may be occurring in more recent times, in that students see an initial S&T education as a channel to a career in an altogether different area—finance, consulting, business, etc. This is not altogether a bad thing; in fact, for some time now, it has been known that few IIT graduates have stayed in engineering as a career, and have succeeded in other fields, particularly in the private sector.

In a sense, this was the original vision of the IITs: to generate Indian "technocrats" who would take on leadership roles in technology and industry, and hence contribute to the economic development of the country. As it happened, a large proportion of these graduates accomplished this, but overseas. Whether this trend is changing and more engineering graduates are returning to India after their education (and perhaps a brief career) overseas is an issue that needs to be explored.

From the perspective of organizations concerned with S&T, such as NSF and national S&T agencies, these trends raise an important question. To what extent is advanced S&T education to be seen as precisely that, preparing students for careers in their respective fields of S&T, and to what extent is it an intellectual training ground that prepares these students for a broader panorama of career options? And which of these two is the more important from a long-term economic development perspective?

This issue has several implications in terms of financing of graduate education, establishment of new institutions, and the types of support that can or should be provided to students.

Furthermore, if indeed one result of this trend is a downward pressure on the supply of trained S&T graduates further aggravated by the poor employment prospects in S&T areas, measures need to be taken to address this issue. Rao (1998) points to the "assured placement scheme" of the Department of Atomic Energy in India, which first brings graduates into their own training school where they are coached for a year in an advanced field of importance to the department. They are then assured of a job at the end of the year. A similar approach could be adopted by private industry in India as well.

## Recent Economic Crises

Some mention has been made of the impact of the recent economic crises in Asia on the ability of students from these countries to pursue advanced education in the United States and on the circulation process.

The most immediate effect of the Asian economic crises would be on the ability of foreign students to afford education in the United States without financial support of some kind. There is anecdotal evidence that this is taking place (Honan 1998), partly due to rising costs of education in the United States and partly because other countries are recruiting students more vigorously. Nine of the 10 countries that send the greatest number of students to the United States are Asian (Canada is the only non-Asian country). Additionally, the financial crisis has forced many Asian students to seek cheaper housing, get part-time jobs, and transfer to colleges in other countries. To what extent this overall trend is reflected in trends in S&E graduates requires research.

The Asian crisis would have had a greater impact on the plans of students from the worst affected countries (South Korea, Thailand); its effects on Indian students may have been less. However, the India rupee has also been losing value steadily, which is likely to have an impact over time. NSF analysis of foreign doctoral recipients and their stay rates in the United States shows that India and China have the highest rates; this is likely to continue for the reasons outlined earlier.

The Asian economic crisis does highlight one issue that bears deeper consideration—the relationship between productivity-driven economic considerations and the demand for and behavior of S&E graduates. The argument has been made that a major reason for the downturn in these economies was a lack of long-term and targeted investment in productive wealth-generating efforts that would add value to local resources and generate sustainable competitive industries. Instead, much of the investment was going toward speculative ventures, real estate, and debt financing of noncompetitive industries, where the need for highly trained S&E personnel is low. One would then expect that most of the jobs and opportunities for S&E personnel would be in academia and the government. In India, this has certainly been the case, given the low demand for S&E personnel in the private sector. Yet it is in the private sector, where their knowledge can be applied to the development of competitive technology-based enterprises, that their full value should be realized—at least in terms of contributions to productivity.

Furthermore, in an economic downturn, not only does private industry cut back on R&D expenditures, but the government typically also cuts budgets in S&T-related areas. All of this has the net effect of reducing even further the demand for S&E personnel in S&E careers. The only major source of demand under these conditions would be overseas employers (such as in the United States), and that would be subject to the sector priorities in those economies. Thus, the growth in the information industry in the United States (and its counterpart in India) is drawing an increasing number of Indian engineers because of both its economic attractiveness and the decline of opportunities in other fields.

Thus we have a downward spiral effect where past economic policies, based on a lack of focus on the role of S&T to economic growth (and the consequent low demand for such skills), produce conditions that further deteriorate this demand. This subject—the relationship between economic policies and demand conditions for S&E personnel—requires further investigation.

In the past, the implications of broad economic trends and conditions have not been stressed in the analysis of educational needs in S&E and patterns of S&E education. In today's more integrated and dynamic global economy, it would be prudent to bring these factors into an analysis of this critical issue. This in turn means broadening the disciplinary base for the study of S&E education to include expertise in technology and economic development, economic policy, technology commercialization, and competitive strategy, among others.

## Issues for Further Research

Clearly, there are a number of issues that need to be addressed to develop a more current and accurate understanding of the situation today and in the future with respect to S&E graduate education. In the case of India, the lack of data is in itself a problem, but the types of data that need to be gathered and the relationships that need to be studied also need to be reassessed. Some of these are summarized below.

### Comparative Data on Distributions Across S&E Fields in the United States and India

Of particular interest here would be the changes in distribution between new fields (e.g., IT) and traditional areas, as well as distribution changes within fields (e.g., food processing). In addition, data on distribution between the United States and India in terms of degree recipients, and the employment locations of both groups by field, would provide better insight into current trends.

## Data on Economic Conditions and Employment Choices of S&E Graduates

The correlation of broad economic indicators, such as those used by the World Bank and the United Nations Development Programme, as well as assessments of the competitiveness of different countries (e.g., the *World Competitiveness Report*), with employment paths and patterns of demand for skills in S&E would provide very useful data for future education planning and reform. Of importance here is the need for a conceptual framework that builds upon analytical principles in economic development and allows propositions to be developed about the relationships between economic development dynamics and career patterns and choices of S&E personnel in India.

## Time-Series Data on Career Paths of Indian Scientists and Engineers

As discussed earlier, many Indian engineering graduates are now in senior positions in other fields—business, consulting, finance, etc. This is an important trend both in terms of how we evaluate graduate S&E education and how we develop new educational programs and policies. Just as the IITs were established based on a "technocratic" vision, there may be an emerging need for educational institutions to integrate S&E with such areas as entrepreneurship, innovation, economic development, and finance to create a new generation of what the United Nations (UN) refers to as "techno-entrepreneurs" for the modern global economy.

## Trends in Sources of Funding

Patterns of funding and the composition of sources of funding for R&D, graduate education, and training is another area for more thorough data collection. This is particularly important because there is an ongoing shift away from public sector funding for R&D and a growing emphasis on technology commercialization. Of interest would be changes in the distribution between Indian and U.S/foreign sources of funding and the types of support being made available from these sources.

## Impact of S&T Policies on Graduate Education

During the 1970s, considerable emphasis was given to the role of S&T policies and policy mechanisms in strengthening S&E capabilities in developing countries. The UN's Vienna Program outlines eight areas where policies needed to be developed in S&T; one is human resources. During the 1980s and 1990s, there was a reduced emphasis on S&T policies, but it may now be useful to assess the impact of the S&T policies developed and implemented by countries such as India on the current situation with respect to S&T human resources.

# References

Department of Science and Technology (DST). 1996. *Research and Development Statistics*. New Delhi: Government of India, Ministry of Science and Technology.

Honan, William H. 1998. For Many Foreign Students, U.S. Colleges Cost Too Much. *New York Times* September 27.

National Science Board (NSB). 1998. *Science & Engineering Indicators – 1998*. NSB-98-1. Washington, DC: U.S. Government Printing Office.

Rao, P. Rama. 1998. Science and Technology in Independent India: Retrospect and Prospect. Address to the 85th Annual Session, Osmania University, Hyderabad, India, January 3.