# India's higher engineering education: opportunities and tough choices*

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*The five Indian Institutes of Technology set up between 1951 and 1961 have established a great reputation for undergraduate engineering education, as good as and, in fact, better than most institutions in the world. But this achievement did not extend to postgraduate engineering education, particularly the training of PhDs leading to cited publications, exploitable patents, innovative products and entrepreneurship. An attempt is made here to analyse the reasons for this and suggest achievable, though tough, pathways.*

**Keywords:** Engineering, global knowledge economy, higher education.

ENGINEERING education spans a wide spectrum from doctoral to first degree to diploma and to craftsman levels to meet the industrial and societal needs. Each level has its role. My coverage is restricted to the first degree to doctoral level in engineering, with emphasis on premier research-cum-teaching institutions, aspiring to become world class in generating innovation, new knowledge and technology, besides mentoring the next generation of technology icons, thereby making India a key player in global knowledge economy.

Setting up the five Indian Institutes of Technology (IITs) (followed by 20 Regional Engineering Colleges; RECs) soon after gaining political independence was a game-changing investment. It paid off by providing world-class undergraduate (UG) engineering education, with their graduates proving to be as good as or better than engineering graduates anywhere. An equally exciting, but challenging and potentially more rewarding opportunity is knocking at present at the Indian higher engineering education. The tasks unfolding, the advantages India possesses, the challenges confronting and possible pathways are examined here. If pursued with a sharp focus, the present young generation with high-quality advanced engineering education through their publications, patents, innovations and entrepreneurship will take India to the centre stage of global knowledge economy. By meeting demanding societal needs at various levels, India will be propelled to be among the three top world economies in a relatively short time.

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## Brief history of engineering education

### *Pre-independence period*

The British rulers set up four engineering colleges in the four corners of India – Roorkee (1847), Sibpur (1856), Guindy (1794) and Poona (1854) to train the engineers needed for the civil and other engineering activities of the day[1]. These four engineering colleges had a total enrolment of 608 students during 1884–85. Each had a glorious record, having produced some of the outstanding engineers of India. Two other prominent institutions were set up nearly 100 years ago – Indian Institute of Science by the House of Tatas (1908) and Banaras Hindu University (BHU) by Pandit Madan Mohan Malaviya (1916) – which again grew to become important institutions. At the time of independence, there were only 24 engineering degree colleges with a total intake capacity of 2570 students[1].

Another major step taken in the pre-independence era was the creation of the N. R. Sarkar Committee in 1945, which submitted a preliminary report recommending the setting up of four higher technical institutions with broad-based education, patterned after the Massachusetts Institute of Technology, USA in the four regions of the country.

### *Post-independence period*

'The scientific approach has changed the world completely. I think that if the world is to solve its problems, it will inevitably have to be through the means of science. The world will ultimately be saved, if it is to be saved, by the method and approach of science.' – *Jawaharlal Nehru*

Implementing the Sarkar Committee recommendations, five IITs were established at Kharagpur (1951), Bombay (1958), Madras (1959), Kanpur (1960) and Delhi (1961) as institutions of national importance by an Act of

Parliament. After a gap of over three decades, the sixth IIT was established at Guwahati (1995) and the Engineering College at Roorkee was first made a University and then as the seventh IIT (2001). In 2008, four more IITs were established at Patna, Jodhpur, Hyderabad and Gandhinagar followed in 2009 by four more at Ropar, Bhubaneswar, Mandi and Indore, making a total of 15 IITs. The older IITs are mentoring the newer ones. The intake of students[2] at different levels into the IITs in 2010–11 is given in Table 1. The degrees awarded (in brackets) and faculty strength in 2009–10 are also indicated in Table 1.

The recent eight IITs have limited UG enrolments (about 100 each) and only nominal admissions at the Master's and Ph D level at present. In the next few years, when they grow to their full size, the 15 IITs will admit about 15,000 UG, 10,000 Master's and at least 8,000 Ph.D. students per year. The Institute of Technology at BHU has been elevated as an IIT; thus there are 16 IITs now. Clearly, IITs contribute a small fraction of engineering graduates in India.

In the next tier institutions, there are 20 RECs which were recently renamed National Institutes of Technology (NITs) with Central Government funding and greater autonomy. It is proposed that 10 more NITs will be set up shortly, making a total of 30 NITs. The 20 NITs admitted 9297 UG and 4569 postgraduate (mostly for a master's degree) students[1] in 2007–08.

Then, there are a large number of State Government Engineering Colleges, often affiliated to a University and having a limited or no autonomy about curriculum, examinations, degree granting, etc. The great demand for engineering and technical education has led to the mushrooming of the large number of private engineering colleges, many started by politicians or as money-making ventures (Table 2)[3].

This phenomenal growth has led to a steep decrease in quality, though some of them are accredited by the All India Council of Technical Education (AICTE) or other bodies but lack autonomy in most matters and do not have adequate number of qualified teachers and infrastructure. According to the National Association of Software and Services Companies (NASSCOM), only 15–20% of the graduate engineers are employable[4].

Recently, the Indian Government has taken fresh initiatives to increase the number of Indian Institutes of Information Technology (IIITs), Indian Institutes of Science Education and Research (IISERs) and enable government departments such as Defence Research and Development Organization, Department of Atomic Energy, Indian Space Research Organization and Council of Scientific and Industrial Research to train people at the postgraduate level and award their own degrees.

**Table 1.** Intake and graduation in IITs

| | Under-graduate | Master's | Ph D | Faculty strength |
|---|---|---|---|---|
| 7 Older IITs | 6681 | 7082 (3930) | 1660 (959) | 2943 |
| 15 IITs | 7678 | 7152 | 1799 | 3138 |

**Table 2.** Number of engineering colleges and intake[3]

| | 1977–78 | 2008–09 |
|---|---|---|
| Colleges | 562 | 2,388 |
| Intake | 134,894 | 820,000 |

## Advantages and opportunities

India possesses many important advantages which open up major opportunities to enable the country to become a key contributor and play a vital role in the emerging global knowledge economy. Some of the key items in this respect are:

1. India has had a long tradition of erudition and knowledge generation and dissemination from ancient times. However, some of the traditional knowledge, for example, in Ayurveda, is not fully documented or systematized or made up-to-date.
2. In the first decade or so after independence, five IITs were set up, which provided world-class engineers at the UG level and these under-graduates have created a glorious image for themselves, their alma mater and India globally. Graduates from the RECs and a few other institutions have contributed their share in this respect. Leading institutions in India can attract and enroll international students, which will bring about the much needed student interactions and financial inputs.
3. India's median age is about 26 years and nearly 600 million people are in the working age group. This demographic dividend is to be contrasted with the ageing population in most developed economies such as China, European Union, US, Japan, etc. thereby leaving a decreasing fraction of their population as work force. As Sam Pitroda puts it, 'We have the work force for the world, not just for India. Unlike China, India's growth will be driven by domestic consumption'[5]. If we take the right steps and make rapid progress in quality technical education, we can provide a well-trained, innovative workforce not only to India but possibly other countries. Innovation is identified as almost synonymous with young age and good education.
4. English has become the language of the global knowledge economy. Command over English is, therefore, an essential requirement. India is fortunate to have the

largest number of English-speaking people, perhaps next to the US.
5. India has a fairly good and wide information, communication and technology (ICT) network, which is getting better with time. Internationally ICT is playing an increasing role in the education field, so that good quality education can be accessed by people everywhere, including rural areas.
6. The average per capita income and therefore, the middle income population in India is growing rapidly. This translates into market for more manufactured goods and, even more importantly, demand for quality education. More people recognize the importance of quality education as the way to move ahead in life and have the resources and willingness to spend on good education.

These advantages augur well for India and significant progress can be made if the various stake-holders seriously pursue the goals with right, bold steps and overcome the obstacles on the way and the Government gives 'real' autonomy to the select institutions.

## Challenges

The response to the first wake-up call (1950) was the creation of the 5 IITs and 20 RECs. The IITs have earned and sustained an international brand name for excellence in the case of UGs. The contributing factors for this are: the entering students are outstanding, having come through a gruelling entrance examination and (with a success rate of 1–2%, more selective than the best institutions in the world where 1 in 10 is the more common norm, e.g. 7% at Harvard[6]); broad-based flexible curricula; some superb inspiring teachers; open evaluation system and great autonomy. These IIT graduates are a match to the best in the world and better than most. Having said this, we all also know that our higher engineering education is not where we would like to see it in comparison to the world knowledge scenario. We should be sanguine to identify and quantify our deficiencies and failures before we can find possible solutions and pathways, however painful they may be.

The technical education has been examined by top-notch committees, chaired by Y. Nayudamma, P. Rama Rao, R. A. Mashelkar and A. Kakodkar. Each of them made an in-depth analysis, identified the strengths and weaknesses, and made valuable suggestions for overcoming the shortcomings and make progress in the quality of education. If these powerful documents are not enough to propel India along the path of world-class education, the Scientific Advisory Council to the Prime Minister, under the able leadership of C. N. R. Rao, has presented an unbiased assessment and charted out a road map to make India as a global leader in science[7]. However, the political system, bureaucracy, financial constraints, vested interests, etc. play their games, and what gets implemented is often a far cry and a mere shadow of the well-articulated recommendations. The net result is not only limited but delayed progress. However, the present assessment is by a concerned individual.

We are now confronted with the second wake-up call on higher engineering education. It highlights the need for well-trained, motivated teachers and researchers; innovative research for societal needs and new products; joining (and partly leading) global knowledge economy; converting our unique advantages into solid strengths; gaining respect for Indian technological prowess and Indian research. Time is ripe for India to leapfrog to become the third powerful economy.

### *Training of engineers at the postgraduate level*

The postgraduate engineering education forms the core for training of future teachers and researchers and for building up international reputation through publications, patents and entrepreneurs. These professional leaders are capable of transforming the industry.

In Table 3 we compare India with China in terms of various parameters in 2004 (ref. 3).

The percentage of engineering UGs and, more prominently, postgraduates, of the total university student body is dismally small in India compared to China. The number of engineering Ph Ds produced in a country is a good indicator of the generation of advanced knowledge and innovation. Table 4 shows the production of Ph Ds in engineering in comparison with the population and GDP in three leading countries in 1995 and 2009 (refs 2, 8–10).

China, with a comparable population as India, has three times the GDP and produced 12 times as many engineering Ph Ds as India in 2008. Compared to the US which has a quarter of the population and three times the GDP, China produced nearly twice as many engineering Ph Ds as the US. This shows that purposeful actions and leadership can overcome many difficulties.

The number of professionals with doctorate degree and capable of directing research is not growing at a sufficient rate to meet the requirements of academia and R&D institutions[10]. The five older IITs together started awarding about 1,000 Ph D degrees in engineering per year after being in existence for 50 years! Considering the major global role the Indian IT industry has been playing, it is amazing that less than 50 Ph Ds are produced in India in computer science and engineering per year[11]. The ratio of engineering Ph Ds to science Ph Ds is 1 : 4 in India and > 2 : 1 in Japan[11].

### *Publications and patents*

One measure of the vibrancy and sophistication of technical activity in a country are publications and patents.

**Table 3.** Percentage of engineering UG and PG students among university students

| Country | UG Engg. students | University students | % Engg. students of total | PG Engg. students | Total PG students | % Engg. PG students of total |
|---|---|---|---|---|---|---|
| India | 696,609 | 11,777,246 | 6 | 28,000 | 872,161 | 3.4 |
| China | 4,376,167 | 13,334,969 | 34 | 302,296 | 779,408 | 39 |

**Table 4.** Number of Ph Ds in engineering and technology

| Country | Population (billion in 2009) | GDP thousand US$ (2010) | No. of Ph Ds in engineering and technology | |
|---|---|---|---|---|
| | | | 1995 | 2008 |
| USA | 0.31 | 14.1 | | 8,110 |
| China | 1.33 | 5.0 | 1,659 | 15,073 |
| India | 1.15 | 1.5 | 348 | 1,058 |

**Table 5.** Publications and patents from various countries

| Country | Publications | | 2009 % world total | Patents (issued to residents in brackets) | | Patents granted per million people |
|---|---|---|---|---|---|---|
| | 1999 | 2009 | | 1999 | 2009 | |
| World | 610,203 | 783,397 | – | | | |
| India | 10,190 | 19,917 | 2.5 | 2160 (29.3) | 18,232 (32.3) in 2006 | 5 |
| China | 15,715 | 74,019 | 9.4 | 7637 (40.6) | 93,706 (49.7) | |
| Japan | 55,274 | 49,627 | 6.3 | | | 994 |
| South Korea | 8,476 | 22,271 | 2.8 | | | 779 |
| USA | 188,004 | 206,601 | 26.5 | | | 289 |

For select countries, the number of articles published in 1999 and 2009 and the country's share on the world scene in 2009 are given in Table 5 (refs 8 and 11).

It is a sad commentary that India's share of the world publications in science and technology is 2.5% compared to 9.4% for China and 26.5% for the US.

Referring specifically to journal publications from Indian academia[2], there are 5,378 publications from the seven older IITs together in 2009–10 for combined faculty strength of 2,943. A particularly distressing conclusion is that only one in three faculty members produces a Ph D per year (959 Ph Ds for a faculty strength of 2,843 in 2009–10)[2], the journal publications (even without taking into account the quality or impact factor) are less than two per faculty member per year. India's contribution to high-impact research papers[4] is less than 1%. Eighty per cent of the publications from India come out of less than 10% of institutions, suggesting that the bulk of the system is not very productive[10]. In computer science and engineering, a field in which the country is expected to be an emerging leader, only 3.5% of global research output was from India in 2010.

It is significant that nearly 50% of the patents in China are issued to local residents, whereas only about a third are issued to residents in the case of India[8]. Table 5 also shows that Japan, South Korea and the US are the top three countries in terms of patents per one million people. India's position is 52 by that measure; with patents granted in India being about 5% of that for Japan for 1 million people[12].

It is interesting to note that worldwide, 18,414 patents were issued to academic institutions out of a total of 660,328 (about 2.8%) in 2000, which steadily grew to 42,368 patents to academia out of a total of 842,744 (5%) in 2005. The increased share of patents issued to academia can also be due to a growth of 130% in the case of academia compared to an overall growth[13] of only 28%. In the case of China, the number of patents issued to universities has increased from about 10 in 2001 to 260 in 2010, whereas the numbers are 5 and 10 in the case of India in the same decade[11]. The patent activity in Indian academia is low with only 9 institutions participating in 1995, growing to 29 in 2000 (ref. 10). Of the 315 patents applications filed by Indian academia in 1999–2002, 185 were from IITs and IISc and the rest from other institutions[10].

Table 6 shows an interesting correlation between the share of academic R&D and citations on one hand and wealth intensity on the other[11,14].

**Table 6.** R&D, academic R&D and citations of three countries

| | India | South Korea | USA |
|---|---|---|---|
| GDP (in billion US$) | 1,100 | 970 | 14,000 |
| R&D as percentage GNP | ~ 1 | 3 | 2.8 |
| Academic R&D as percentage of total R&D expenditure | 4 | 11.5 | 20 |
| Citations to all papers relative to national GDP | < 0.02 | 0.07 | 0.25 |
| Wealth intensity (PPP-adjusted) per person | 2,900 | 15,600 | 35,800 |

**Table 7.** R&D expenditure (government and business) and R&D personnel[8,15]

| Country | Year | Amount (US$ million) | % GDP | Share of expenditure: Business | Share of expenditure: Government | R&D personnel per million people |
|---|---|---|---|---|---|---|
| India | 2007 | 24,439 | 0.76 | 33.9 | 66.1 | 119 |
| China | 2009 | 154,147 | 1.7 | 71.7 | 23.4 | 715 |
| Japan | 2009 | 137,908 | 3.33 | 75.3 | 17.7 | 5,300 |
| South Korea | 2008 | 43,906 | 3.36 | 72.9 | 25.4 | 3,732 |
| Brazil | | 21,649 | 1.08 | | | |
| USA | 2009 | 401,458 | 2.88 | 59.7 | 31.3 | 4,628 |

Table 6 also demonstrates that India has a long way to go. No wonder that 30 of the 40 world's top educational institutions are in USA and they attract brilliant people to their academia from around the world by offering attractive salaries and working conditions.

## *R&D personnel and budgets*

Table 7 gives the amount and percentage of Gross Domestic Product (GDP; on PP basis) spent on R&D in some countries[8,15].

The R&D expenditure in India is obviously small. Another striking feature is the smaller share of the R&D expenditure provided by industry in India, compared with other countries. In fact, the relative percentage share between the government and businesses is nearly reversed for India relative to other nations[8]. The bulk of the government's R&D expenditure goes to Government laboratories[16] (Defense Research and Development Organizations – 34%, Indian Space Research organization – 17%, Department of Atomic Energy – 11%, Indian Council of Agricultural Research – 11%, Council of Scientific and Industrial Research – 9%, Department of Science and Technology – 8%) leaving a meager 10% for all others[16]. Suitable tax incentives are desirable in India to induce the industry and businesses to invest in R&D, which will increase the quantum of GDP, spent on R&D and also lead to distinct benefits to society at home and abroad in terms of innovative products. This also increases employment of well-trained persons in fruitful research.

The gap in the R&D personnel per million people in 2006 is truly glaring in the case of India and calls for an increase by an order of magnitude[15].

**Table 8.** QS Rankings for five IITs

| | 2010 | 2011 | 2012 |
|---|---|---|---|
| IITB | 187 | 225 ↓ | 227 ↓ |
| IITD | 202 | 218 ↓ | 212 ↑ |
| IITK | 249 | 306 ↓ | 278 ↑ |
| IIT M | 262 | 281 ↓ | 312 ↓ |
| IITKh | 311 | 341 ↓ | 349 ↓ |

## *World ranking of institutions*

The biggest failure of the Indian higher technical education system is that none of the IITs and other good institutions finds a place among the top 300 educational institutions in the world in the Shanghai Jiao Tong University Rankings 2011 and the only institute from India to be listed was IISc at 301–400. In the same rankings, China[17] has three in the top 200, 13 in the top 300, 21 in the top 400 and 35 in the top 500. Of course, USA has 17 in the top 20, 27 in the top 100, 89 in the top 200, 110 in the top 300 and so on[17].

Table 8 shows the rankings of older IITs in the QS Rankings of world engineering institutions for 2010, 2011 and 2012 (ref. 18).

In the QS Rankings for 2011, all the IITs slipped from their position in 2010. In the QS Rankings for 2012, IITB, IITD and IITK slipped further. But IITD and IITK improved their rankings. India is the only BRIC country that has not found a place in the first 200. On the contrary, China, by pumping resources into select universities, has improved its position in the same period (2010 to 2011 to 2012), e.g. Peking University from 47 to 46 to 44, and Tsinghua University from 54 to 47 to 48. For comparison, the top 10 places in this ranking were 6 by

USA and 4 by UK universities. Among the top 50, Asian countries have 3 in Hong Kong, 3 in Japan, 2 in China, 1 each in Singapore and South Korea and none in India. In QS Rankings for 2012, among the top, Asia has Hong Kong 2, Japan 3, Singapore 2, China 2, South Korea 1, again none from India.

In the Times Education Supplement Ratings for 2011–12, only IITB comes in the 301–350 range, compared to 2 places in the top 100, 3 in top 200 and 10 in top 400 for China and 14 in top 20, 51 in top 100, 75 in top 200 and 100 in top 400 for USA[19]. Similarly, no Indian University is among the top 200 for citation per faculty member[19]. Obviously, India has a long way to go to achieve peer recognition. One cannot hide the reality by questioning the parameters taken into account in the ranking system. After all, they are applied uniformly worldwide.

In this connection, it is instructive to closely examine what constitutes a world-class institution. The parameters cited by two persons are outlined below as pointers.

Irrespective of what parameters are used to rank academic institutions, Harvard, MIT, Stanford, Oxford, Cambridge, etc. are among the top few. India does not appear even in the first 200. It is important for India to understand what it takes to achieve excellence and how to retain it decade after decade. Mashelkar[15] identified the following criteria:

1. Absolutely uncompromising pursuit of excellence both in teaching and research.
2. Continuous thrust not only on ‘working’ at the frontier, but ‘creating’ new frontiers. This means ‘to lead’ and not just ‘follow’.
3. An uncompromising insistence on selecting the very best for faculty as well as students on an international scale. The same rigour should be ruthlessly applied for promotion, so that only the most talented and accomplished faculty are retained.
4. Undying commitment to true institutional autonomy in all matters, with no political interference whatsoever.

Alison Richard[20], Vice-Chancellor, University of Cambridge, points out that universities are now judged on an international scale, which calls for some new goals such as

1. Engage in cutting-edge research and at the same time, teach the next generation, the students. Teaching and research are intrinsically bound together, with top researchers inspiring and mentoring their students. In turn, the students themselves inspire and challenge the teachers. World-class universities produce students who will go on to be future leaders in all walks of life.
2. Great universities must allow their researchers the freedom to experiment, succeed and sometimes fail. They must be able to make grand mistakes as well as grand discoveries. It is often through making those mistakes that the grand discoveries are made. A university operating with a completely utilitarian mindset will forego the opportunities that a more open-ended system will allow.
3. World-class universities have permeable boundaries. This means encouraging inter-disciplinary research and teaching, it means working with the private sector, fostering and encouraging international collaboration with world-class universities looking outward and thinking beyond conventional boundaries. We educate students more and more, who will go on to live and work in a range of cultures. We must equip them for this life, partly by what we offer them, who they meet as students and composition of the study body.

Universities must not, however, forget that they are embedded in their countries and regions and not forget that they become the economic hot spots, just as Stanford University’s role in Silicon Valley and Cambridge University’s part in Silicon Fen in the UK[20].

For elevating the better educational institutions in India to a higher level, the Yash Pal Committee made excellent recommendations. While agreeing with most of them, one member of that Committee, Kaushik Basu[21], presented a dissent note on a few crucial issues. One concerns that India, for that matter any government, does not have enough resources to treat all the universities on the same scale to raise their standards. A small number of the better institutions has to be selected and supported on a massive scale to upgrade themselves. This includes giving preferential salaries (by a factor of four to five) and research support to the star professors and researchers compared to the rest. This is precisely the manner in which the US built its great universities and maintains its lead. China is doing precisely this, with visible results. The list of preferred institutions can be evaluated and modified every three years, so that there is competition and opportunity for others to join this league.

The second area, mentioned by Basu, concerns opening the doors of our better institutions to international students, just as all other countries are doing aggressively starting with the US and including new-comers like Australia, Singapore, etc. This will be a welcome source of income besides broadening the horizons of the student community.

I may add that international exchange of faculty is another significant step worth pursuing. The IITs have benefited greatly in the early years of their existence by such collaboration. At present, it can cover not only visiting professors, exchange of students, but most importantly, collaboration involving sharing of research facilities leading to joint publications and patents. As the world is becoming a global village and national boundaries are losing their meaning, international partnering in education and research assumes great importance and is an urgent need for India.

## Arduous pathways ahead

'Small opportunities are often the beginning of great enterprises.' – Demosthenes

Stone[22] summarized the woes of Indian higher education as: India's legendary bureaucracy; universities riddled with corruption; universities nurturing a few 'stars' and overburdened with 'deadwood'; and the prevailing system creating 'followers' and not 'leaders'.

To go from where our higher technical education system is to where we want it to be, there are a number of serious challenges we face and major obstacles we have to overcome and some possible solutions are pointed out here.

### *Entrance examination*

Students seeking admission to engineering degree colleges have to take several entrance examinations, which is taxing for young persons and often results in neglecting their normal high-school studies. The IIT Joint Entrance Examination (JEE) has proved itself to be an excellent calibration test and is currently taken by over 500,000 aspirants of whom only about 7,500 enter IITs. One may consider reverting to the practice of the two-part JEE test which was used till recently. This gives greater choice to colleges in specifying their criteria for admission. Even with minor modifications, this should serve as a national entrance examination for all engineering degree institutions. Colleges should have flexibility to declare their criteria for admission which may include weightage given to performance in JEE, high-school performance, etc. State institutions may specify the percentage of candidates admitted from the state, but based on the same criteria. This complex subject has been discussed by Mehra[23]. Many countries have a single entrance test for admission to degree programmes.

### *Quality*

The rapid expansion of engineering institutions has led to a steep deterioration in the quality of education due to acute shortage of numbers and qualification of the faculty, poor laboratory and library facilities and other infrastructure as well as limited or absence of autonomy. These problems may be severe enough in the case of IITs, but are major road blocks for the other institutions. Though an accreditation by the All India Council of Technical Education and other bodies exists, it has proved totally inadequate and is reported or suspected to harbour malpractices. Further, the accreditation report card of each college should be posted on the web, and the colleges should be required to include this information in their bulletins, which will be of great help to the students and the parents on one hand and employers on the other.

Table 9 highlights the serious lack of quality in technical education[11].

### *Postgraduate education and research*

Unless our premier institutions devote to the PG programmes the same zeal that they did in their early years to build a world-class UG curriculum and sufficient financial and employment attractions are instituted, they cannot produce good quality Master's and Ph D degree holders. Not enough B Techs opt for PG studies (less than 2% in the case of IITs). A comparison of output at various degree levels in India and the US is instructive in this respect[11] (Table 10).

The number of students at the first degree stage is larger in the case of India because the private institutions enroll students for the first degree, but have no facilities for PG courses. The small percentage of Indian engineering UGs pursuing PG studies is directly related to well-paying industry jobs available to students from good institutes and hence they lack motivation[6]. It is essential to enlarge quality PG education in India by making it attractive, exciting and rewarding.

Reviving the Quality Improvement Programmes for practising teachers on an expanded scale (say 1000 per year) with more attractive terms is an essential step. Considering that most engineering college teachers have only a Bachelor's or at most, a Master's degree, each engineering college, private and public, should be encouraged to depute one faculty member per year for obtaining an advanced degree. Such a move has multiple benefits: availability of better qualified teachers, postgraduate students for research in premier institutions and diffusion of best pedagogic methods and research orientation into the engineering education system.

The industry and R&D organizations seconding some of their engineers for PG studies with suitable incentives is also a step in the right direction and is of mutual benefit. Research projects may be jointly selected and will have two guides, one from the sponsoring organization and one from academia. Part of the research may be carried out in the sponsoring organization if suitable facilities are available. The time is ripe for such an initiative because the R&D activities have expanded significantly in the recent years in the Indian industry as well as in the R&D centres set up by multinational corporations.

The demographic dividend of countries like India is leading to outsourcing for advanced technologies and innovative solutions by the advanced nations to the developing countries with quality education and youth. As a

**Table 9.** Total and quality student intake

| | | |
|---|---|---|
| No of colleges (~ 90% private) | 3,400 | |
| Total intake (~ 97% in private colleges) | 1,500,000 | |
| 7 + 8 IITs intake | 7,500 | (0.5%) |
| 20 + 10 NITs intake | 15,000 | (1%) |
| Other good universities/institutions intake | 17,500 | (1.2%) |
| Total intake in quality institutions | 40,000 | (~ 2.7%) |
| Less than 3% graduates from good institutions[11] | | |

**Table 10.** Engineering students at three levels in USA and India

| | USA | India |
|---|---|---|
| Bachelor's | ~ 75,000 (5% of India) | ~15,00,000 |
| Master's | ~37,500 (50% of India) | 75,000 (5% of Bachelor's) |
| Ph D | 7,500 (500% of India) | 1,500 (0.1% of Bachelor's) |

**Table 11.** R&D personnel employed by US companies at home and abroad

| | Employed | |
|---|---|---|
| Year | USA | Abroad |
| 1994 | 625,000 | 102,000 |
| 1999 | 647,000 | 123,000 |
| 2004 | 716,000 | 138,000 |
| 2009 | 739,000 | 267,000 |

result, a number R&D centres established by multinational corporations in India have grown from a paltry 50 in 2002 to 150 in 2006 (ref. 10) and over 760 more recently[15]. The companies include IBM, Microsoft, CISCO, Intel, Texas Instruments, Pfizer, LG, Philips, Eli Lily and Unilever among others[10] and have employed over 160,000 people[15]. This is a vote of confidence in India's emerging position in innovative, cutting-edge technologies. The positive implications of this are: India is turning from an importer of technologies to an exporter of advanced technologies and products and secondly, turning brain-drain to brain-gain through brain recirculation[15]. The flip side is that the high-quality R&D personnel are shifting from the Indian R&D and academic establishments to these new centres attracted by better pay packets, perks, equipment and infrastructure[10]. This should undoubtedly be taken as a wake-up call by the Indian institutions to improve the salaries, infrastructure and stimulating work environment[15].

The US based multinational corporations are rapidly shifting their R&D operations abroad as reflected in the deployment of R&D personnel both at home and abroad by these companies[24] (Table 11).

**Table 12.** Trend of R&D expenditure (in billion USD) in different countries

| | Year | |
|---|---|---|
| Country | 1996 | 2010 |
| USA | 200 | 400 |
| Asia-10* | 125 | 399 |
| European Union | 140 | 298 |

*Asia-10: China, India, Indonesia, Japan, Malaysia, Philippines, Singapore, South Korea, Taiwan and Thailand.

There is about 3% increase in the R&D employees in the US compared with near doubling abroad in the last 5-year period. The reasons for such a shift are many: lower costs, greater availability of well-qualified people, easier adoption of products to local needs and expanding markets.

In this connection, the important trends in R&D expenditure (in billions of US$) in recent years are instructive[24] (Table 12).

The R&D expenditure has more than tripled in Asia-10 between 1996 and 2010, whereas it has only doubled in the US and European Union.

Collaboration should be established between Indian academia and universities abroad for exchange of research students and for joint research. The facilities and research environment will lead to better quality research while building academic collaboration. This model was implemented by China with great success.

One of the key elements for the success of the original four IITs as excellent academia is the close collaboration with institutions abroad. Such close academic linkages are sorely missing or in low key at present. This situation needs urgent attention and purposeful remedying if Indian institutions should climb the ladder of academic excellence. Exchange of faculty and postgraduate students and joint research on a continuing basis are needed. The number of internationally co-authored publications is one index of such partnership. It is 21.5% in the case of Indian publications, less than the world average[16] of 35%. The presence of 22 million Indian diaspora abroad, mostly in the US in key positions in academia, R&D institutions, cutting-edge industries and start-ups makes such coupling easier now than ever before. Each leading institution in India has a significant number of their alumni in a position to contribute and assist in this process. For example, the Indians who played a key role in transforming Silicon Valley and Route 128 as hubs for innovative start-ups can infuse entrepreneurial excitement in and around the leading Indian academia.

Lack of adequate high-quality educational facilities is making a large number of Indian students go abroad for higher studies. The numbers grew from about 40,000 in 1999 to 140,000 in 2007, involving an outgo of about $ 13 billion[25]. This problem can be addressed by increasing the number of quality institutions in India and attracting foreign universities to open branches in India.

Each faculty member in the premier institutions should be required to produce one Ph D student per year on the average. With the present faculty strength of nearly 3,000 in the first seven IITs, their Ph D output should be close to 3,000 per year from the present 1000 per year. In Tier-II institutions, the emphasis will be on UG and postgraduate education. These Master's candidates then move on to the premier institutions for their Ph D.

Concentrated and intensified effort should be made to increase the number of peer-reviewed publications and highly cited papers by faculty in the premier institutions. An analysis such as that of Institute of Scientific Information, USA, shows that the number of research publications per Indian faculty member in 1995 was around one compared with over six per MIT faculty. The publication record of other public and private institutions is worse[26]. A carrot-and-stick approach is needed, whereby productive, innovative faculty are rewarded by extra research funding, promotions and special faculty Chairs. At the same time, faculty members falling short of the expected research performance and Ph D guidance need to forego promotions and maybe encouraged to move to other institutions where teaching is the primary activity. Similarly, our engineering academia should strive for patenting innovative R&D activity both in India and abroad. This calls for a special patenting and marketing cell in our institutions to assist the innovators in handling the details in this area. The persons whose innovations resulted in patents and particularly when they are licensed for exploitation should be rewarded in a suitable manner. The innovator may be encouraged to become an entrepreneur in an innovation park attached to the institution.

Another major lacuna in our premier engineering institutions is the minimal academia–industry interaction. The World Economic Forum (2008) reports that India ranks 43 in terms of industry–academia interaction compared to China (23), Japan (21), South Korea (12), UK (9) and the US (1)[15]. Since this plays an important role in course content and research projects assigned to students being made relevant to the needs of Indian industry and society, effective steps should be taken by both sides to make it mutually beneficial with appropriate incentives for faculty and attractive returns for the industry. Besides one day a week for industrial consultancy during the academic sessions, summer vacations offer a greater flexibility for this. Fifty years ago, in the early period of IIT Kanpur, an Innovative Summer Industrial Opportunities Programme for Faculty[27], was successfully implemented in which faculty spent up to two months of the summer working in the industry on pressing problems identified by the industry. A faculty member with an appropriate background was seconded to the company. Large, small and public sector industries participated, and in one case, a company in the UK also took advantage of it.

### *Faculty shortage*

The shortage of faculty both in numbers and in quality is the most serious problem facing higher engineering education system and is the most difficult, but at the same time, most urgent challenge to be tackled. Even premier institutions such as the IITs have faculty shortages of 25% or more and the situation has persisted for a long time. The other institutions face a more grim problem. It is not at all uncommon for a person who graduated with his first degree (BE or B Tech) to start teaching in the following academic year! A Ph D degree and a respectable publication and research record are essential for the faculty in the premier institutions, while other colleges may relax this requirement by having more faculty members with a Master's degree. Rama Rao[11] has pointed out that for an annual student intake greater than 1,500,000, there is a faculty shortage of about 80,000 (for a faculty: student ratio of 1 : 15). Of these, about 60,000 persons are needed with a Ph D and another about 25,000 with a Master's degree. The increased student intake and a large number of new colleges being opened make the faculty shortage even more serious, having a direct effect on the quality of education. The shortage of an adequate number of qualified teachers is so serious that a multi-pronged attack on several fronts has to be mounted on an urgent basis before our hopes are dashed and the technical education system collapses.

Rehiring retired faculty and inducting qualified engineers from the industry and R&D institutions as adjunct faculty is an attractive possibility. Even more important is the provision of financial and other incentives offered to induce qualified persons to enter the teaching profession. These carrots should include provision of start-up grant for research, laboratory space, allotment of PG students, besides financial perks which may include travel and moving expenses at the joining time as was done in the early years of IIT, Kanpur. For existing faculty, rewarding hard work and excellence should be performance-based, which would also bring in competition. The rewards may include J. C. Bose professorship, Swarna Jayanthi research awards and supplementary salary in the form of name Chairs funded by alumni donations. In order to encourage research and industrial consultancy, faculty should be allowed to charge three months additional summer salary to research projects or to industrial consultancy.

Even these essential measures are not enough to bridge the faculty deficit in numbers and quality and certainly not soon enough. So what is the way forward? Luckily, there are impressive advances in information and communication technology (ICT) in recent years, which can be exploited to transform the knowledge dissemination process. With wide-band communication channels available at affordable cost (in fact, at a decreasing cost with time) all over the country, lectures delivered by excellent, inspiring teachers in our premier institutions (e.g. IITs) can be beamed into classrooms in any engineering college in any part of India, with facility for the students to ask questions. In addition, there are rich resources such as open course ware from MIT, which are available free. There are National Programme on Technology Enhanced Learning (NPTEL) courses offered by the 7 IITs and IISc, and use of National Knowledge Network (NKN) with the possibility of using You Tube can revolutionize the spread of quality education[11,16]. This approach has great promise not only for meeting the teacher shortage but, even more importantly, in improving the quality and pedagogy of engineering education across the nation.

Induction of new faculty is an urgent, but difficult, task. In general, the ambience for active and exciting research should be created and nurtured. A visiting professor program with institutions abroad should be seriously pursued. Alumni who are teaching abroad can provide good links for this.

### *Brain drain to brain recirculation*

A recent survey showed that every third IITian went abroad, mostly to the US, from the graduates of 1964 to 2001, though the trend is changing more recently. It was further found that one out of four of them has become an entrepreneur. For example, in the decade 1995–2005, 26% of all the higher technology companies started in the US by immigrants had Indian founders[28]. Many in India took the attitude that only a small number went abroad and resigned to the idea of inevitable brain-drain. But what is not realized is that 1% of the top talented people possessed 90% of the intellectual energy[15]. A recent UNDP report estimated that 100,000 Indian professionals leave the country every year and this corresponds to a resource loss of US$ 2 billion per year for India. Imagine the potential economic gain these talented people can make to India. The rich resource of Indian diaspora abroad who have excelled in technology, entrepreneurship, academia and business should be tapped by suitable inducements to enable the premier engineering institutions in India to leap-frog to join the elite club of MIT, Stanford, etc. Bringing some of them on the Board of Governors of our best institutions can bring in fresh air and energy and novel but proven strategies.

### *Autonomy*

Our premier technical education institutions need much greater autonomy in curricula, recruitment of students, faculty and staff, financial matters, including alumni and industry funding and administrative issues. The Board of Governors of these institutions should have total freedom and the last word on what affects the institutions, including the choice of Director. The premier institutions need great leaders who can enthuse their colleagues to perform beyond their limits. P. K. Kelkar did this in the case of IIT Kanpur in its first decade. The role of the government should be minimal and distant and this includes the choice of the Chairman and members of the Board of Governors and the Director.

## Conclusion and way ahead

### *Recommendations*

India's higher technical education is good in small pockets, but far from world class. The bulk of it is of poor quality, producing graduates many of whom are unemployable. The main reason for this pathetic situation is rapid expansion of the education system without adequate number of qualified teachers, shortage or absence of infrastructure and lack of autonomy in all aspects of the technical education system. Other contributing factors are: poor linkage with industry, poor visibility in terms of publications, patents, new products and low or no international collaboration in teaching and research.

1. In order to rectify this pathetic situation and enable India to have at least a few world-class institutions calls for some hard decisions. Recognizing that India does not have the resources to raise too many institutions to world class level, it is essential to identify a small number (possibly five) of the best institutions to start with and provide all the support needed in terms of world-class faculty, outstanding students, large postgraduate and research programmes, excellent infrastructure, totally independent Board of Governors with no government participation and interference, freedom to raise corpus funds from alumni (here and abroad), industry and business for enhancing of salaries of faculty and improve infrastructure, and build extensive international collaboration at the faculty, student and research levels. The directors should be eminent scholars, and chosen by the respective Boards and should not be burdened with mundane tasks such as campus residential maintenance, etc. The initial five institutions can be chosen from among the 7 original IITs, IISc, Institute of Chemical Technology, Mumbai, among others. At the end of 3 years, these five institutions will be critically evaluated by international groups of experts in terms of academic content,

research quality and quantity, publications and patents, and awards and funding received. In the second round, other institutions will also compete so that a set of ten institutions are nurtured to raise their standing in the world knowledge community. This process will be continued every 3 years. The initial goal is that at least some institutions break into the top 100 world-class academia and in the next round for some to find a place among the top 50 and so on. At the end of the first decade, one or more institutions should be among the top 20 in the world. China, Singapore, South Korea, etc. have followed this strenuous exercise and demonstrated that their select institutions did climb the stringent quality ladder, based on massive support and unlimited freedom.

2. The second crisis issue concerns shortage of qualified teachers. Responding to great demand for technical education, engineering colleges have mushroomed (mostly in the private sector) leading to teacher shortage. This issue is also linked to few people going in for postgraduate education, preferring an industrial job. Every possible means should be employed to increase the output of engineers with Ph D and Master's degrees. The number of Ph Ds guided, number and quality of publications should be major factors in the evaluation of faculty members, both for rewards and for stagnation. The avenues include: expanded quality improvement programmes for working teachers, visiting faculty from abroad, and adjunct teachers from industry and R&D institutions, improving the salaries of teachers based on performance, obtaining and securing star teachers with substantially larger emoluments, etc. Another major step in this direction is a more imaginative use of ICT to make good lecture and course ware more widely available to the technical education system. The NPTEL courses started by IISc and 7 IITs, use of National Knowledge Network, MIT Open Course ware are some of the obvious candidates to improve the quality of technical education.

## *Two examples*

A strong case is made here for raising a few Indian institutions to a world-class level. There is likely to be serious skepticism about achieving this in view of the great constraints, road-blocks, interferences and past record. I may point out two examples of success which give some hope and confidence.

1. The Institute of Chemical Technology, a department of University of Bombay. It was established in 1933 with Robert Forster as the Head of the Department (1933–38), followed by K. Ventakaraman, who nurtured it and was later taken to great heights by Man Mohan Sharma. The following data for 2009–10 illustrate its great success as the best PG centre in India and comparable to the best in the world[11]. It received government grants of Rs 10 crores supplemented by private funding of Rs 6 crores per year and project funding of Rs 5.5 crores (government) + Rs 17 crores (industry). It graduated 205 at Bachelor's, 161 at Master's and 100 at Ph D level. With faculty strength of 69, of whom 45 are eligible to guide doctoral candidates, it works out to a record of over 2 Ph Ds per faculty per year and about 3 M Techs per faculty per year. In that year, it had 182 cited publications (more than 3 per faculty) and 18 Indian and 9 foreign patents filed. Rightly, it is now a Deemed University.
2. Established in 1854, College of Engineering, Pune, is one of the oldest engineering colleges in the country. It is a state Government-supported college and affiliated to University of Pune. It has had illustrious alumni including Mokshagundam Visvesvarayya, C. K. N. Patel (US presidential Medal of Honor awardee), Thomas Kailath (Stanford University), Lila Poonawala, Bajajs and Vijay Kelkar. However, all the inevitable constraints brought this college over the years to the level of any other State Government college. The Maharashtra Government took an unusual step of appointing a Committee to examine the actions needed to elevate this institution. The Committee's recommendations were completely accepted and immediately implemented by the State Government. As a result, it is given great autonomy, has an independent, competent Board of Governors, chaired by F. C. Kohli, which takes all decisions, has appointed an outstanding academic in A. D. Sahashrabudhe, as Director and is given a great deal of autonomy coupled with responsibility. Under the dynamic leadership and great dedication of the Chairman and the Director, the faculties are charged up with enthusiasm and a great transformation has taken place on all fronts. One measure is that in the ratings of engineering colleges by *India Today*, *Outlook*, etc. the college has moved in a short span of 5 years from nowhere to be in the top 20, ahead of even some IITs.

The progress of these two institutions – a University Department and a state engineering college – has demonstrated that leadership, dedication and autonomy can indeed elevate Indian technical institutions to great heights. Thus, there is full justification in cherishing that our best institutions can quickly climb the quality ladder to join the ranks of the world-class academia, if the following conditions are created: total autonomy, independent, empowered Board of Governors, an outstanding academic as head, liberal funding by the government supplemented by private donations, good faculty with some stars, high-quality students and good infrastructure.

In conclusion, India's strength lies in our next generation. We have young, energetic and large human capital. We have good intellectual capital which requires improved quality education and careful mentoring with right strategies for higher technical education. Then India will become one of the world's largest powerhouses of global knowledge economy. The present young generation is on the threshold of most exciting opportunities for innovation. We must realize our potential as competent individuals and as a proud nation capable of leading the world in many frontier areas of research and innovation.


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