Fuelling the Indian economic engine by retooling Indian technical education

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Improving a nation's higher education system in science, engineering and technology is directly correlated to its economic health and the social development of its population, and one of the reasons India has lagged in this regard has been its seemingly outdated and unplanned technical education system that is often driven more by fiscal motives than addressing the needs of the nation. Herein, it is established that the American model of technical education is inherently superior to models in place in other nations and that this model was predominantly shaped by the unique conditions that permeated American society at the time of its inception. It is then suggested that India remodel its technical education along the lines of the American higher education system, but do so with suitable modifications to assimilate the realities facing Indian society. Accordingly, steps to achieve this challenging transformation are prescribed. Resuscitating the Indian higher education system necessitates considerable ingenuity and prudence on the part of its administrators and planners, and the purpose of this article is to stimulate wider discussion and introspection within Indian academic and government circles.

Keywords: Curriculum restructuring, education, innovation, science and engineering, university.

WHETHER it was a movie that lampooned the stifling environment of engineering institutes in the nation, an Indian-educated Nobel laureate, or some of the government's ambitious new reforms in the sector, education has garnered considerable press in recent months. While some experts argued that our technical institutes suffocated creativity instead of germinating it, to some, the prolific success of Indian students in the extremely competitive and highly innovative environments of Silicon Valley suggested that our technical education system had few flaws. If a prominent business leader weighed in with his cautionary views, India's staggering economic growth was quickly touted to placate fears about the poor quality of Indian technical professionals. When some claimed that the rising migration of students trained in science and engineering to the financial sector revealed a disturbing trend about the ability of some of the nation's premier institutes to sustain student interest and morale, others disagreed whether this happened, while a few felt this was merely an artifact of market dynamics. The sea of opinions was as endless as it was polarized.

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Putting an end to the debate

Even if we were to momentarily agree that our technical education system does indeed prepare our students to confront many of the grand challenges that lie in wait for them once they graduate, that our universities successfully sustain student interest, and that students are motivated to pursue challenging careers in science, engineering and technology, what should we make of problems such as food shortages, declining energy reserves, natural calamities, environmental destruction, an incessantly rising population, lack of clean water, absence of civic planning, rampant spread of epidemics, rising unemployment, disparate regional development and the ensuing exodus of people to regions of prosperity, and, lastly, the ill-defined and largely nebulous regional and linguistic aspirations that these migrations have precipitated?

Some might argue that these problems are well beyond the scope of science and engineering, but many of the world's best and brightest scientists and engineers would beg to differ[1,2]. The centrality of India's technical workforce to India sustaining its breakneck growth and eventually triumphing over all these ills is beyond doubt. That India has yet to witness appreciable improvement in these sectors suggests that our technical professionals are woefully out of their depth. A revolutionary transformation in the manner in which our scientists and engineers are educated is essential, perhaps even unavoidable.

Imitation as a tool for development

As is the norm for social debates in India, the blame eventually trickles down to that much-maligned species – the Indian politician; and the Indian government has been regularly faulted for the lack of significant investments it has made or attracted in the higher education system. University administrators too unabashedly deflect responsibility for the poor quality of education that is imparted at their institutions to the resource constraints imposed upon them, and when viewed from this perspective, it is not all that surprising why the issue of reservation of seats in educational institutes for members representing specific groups proved to be so provocative. But should the Indian government really be held accountable for these developments?

Some critics frequently contrast India with nations of the industrial world. They contend if democratic nations such as the United States, Britain and Germany can witness the bloodiest wars, a crippling economic depression and some of the worst social catastrophes in history and still rise to positions of preeminence in the world order, India should be able to achieve the same by adopting similar, if not the same development paradigms. They point to Finland and its rapid ascent in the world order by its aping of the policies of other developed nations, notably the science and technology policies of Japan[3]. 'Imitate the best and you'll eventually get better' is what they prescribe.

As was the case with several formerly developing but now developed countries, imitation was absolute with little deviation from the borrowed policies. Not to be left behind, several of India's development policies too have conformed to those of the bandwagon. However, when development is slow or sometimes inconspicuous, Indian policy makers bemoan the size, complexity and idiosyncrasies of Indian society and cite the maturity of social structures and organizations in the West and the apparent lack thereof in India as one of the reasons for the persistence of many of these problems. In fact, it has been observed that a nation's goals, priorities, instruments for development and, most importantly, results exhibit remarkable convergence with those of others despite immense differences in history, culture, political contexts (different from political system, which refers to the form of governance) and the timing of their entry into the industrialization process.

A brave, new world

So why have not most Indians reaped the benefits of development despite several decades of reforms and execution of policies that were seemingly successful in other nations? Tersely stated, the global economic equation today is vastly different from what it was when the United States had just embraced industrialization and a nation now has to look inward as well as outward while charting its economic agendas. This could unforeseeably scramble national development priorities, especially for nations such as India, and wanton imitation by present-day India of the executive policies of industrialized nations when they were at a similar stage of development will yield only minor benefit.

Smaller developing nations that are relatively dissociated from the global economy, if astutely governed, can afford sizeable periods of economic insularity from the world in an effort to build their institutions. India's large size and relative economic maturation – largely attained over the past two decades – predisposes her to be an imminently influential player on the global stage. This inadvertently complicates the task of India's policy makers – how to remodel the nation's institutions without severing the links to the global village is a monumental challenge. Some critics will duly raise comparisons with China and her successes in achieving this tricky balance. The vastly different political systems of India and China make comparisons between both nations in aspects such as national development ring hollow. India's problems are unique – it is afflicted by ills that plague both, the richest and poorest nations on the planet. A holistic development plan that encompasses all economic and social rungs is vital if the Indian experiment is to succeed.

The ills affecting India

As shall be discussed later, besides being immensely promising, reliance on science and technology for addressing its problems does not require the nation or any of its institutions to dissociate from the global ecosystem, and India could easily achieve the holistic development that she aspires via the judicious application of scientific and engineering acumen. This task, though rational in its purport, is extremely challenging, more so for India, owing to her historic predilection for incremental process innovation – a fondness that can be ascribed to Indian science and technology innovation being hitherto almost exclusively industry-led. Not that process innovation is a flawed approach – it has contributed heavily to the Indian economy over the years and continues to do so even today – but it is past its sell-by date. Moreover, years of parochial planning subscribing to the 'if it isn't broken, don't mend it' mindset has considerably harmed the Indian economy and technical workforce. Public sector companies were only too happy to provide employment but were least bothered about the quality of their services and goods since no competition existed in these mega-industries. With a labyrinth of protectionist measures, including customs tariff, there was no scope for product innovation. In the words of former Prime Minister Rajiv Gandhi, India could not even produce a quality paper pin. It was hoped that the so-called reforms and relaxation of the permit-raj in early 1990s would change this scenario but these reforms did not prove to be as successful as initially hoped. Product innovation has been hitherto conspicuously missing from India and the absence of reforms in her innovation systems and academic institutions has left India's scientific and engineering communities poorly equipped to realize sustained economic growth while addressing some of the glaring challenges presented earlier.

Although some of the fault lies with central and state funding agencies for their sluggish approach (often mistaken for being conservative), a bulk of the blame must be borne by India's professional bodies and university administrators. The administrators are particularly guilty of propagating the rigid and tedious bureaucracy that is malignant in their universities. Of course, they cannot be blamed too much because the bureaucracy and lack of autonomy made their jobs much difficult but the severity of this situation becomes evident when one learns that seemingly straightforward tasks such as procuring equipment for research were beset with a web of bureaucratic permissions that simply delayed the project or marred its outcome. For example, about two decades ago it was truly frustrating for academics to import equipment in India. If a research project required use of sophisticated equipment that was not manufactured in India, the researcher was first asked to apply to the Director General of Technical Development (DGTD) and provide documentation that conclusively proved that no Indian instrument maker manufactured the equipment, following which, a long review of the case was initiated – the duration of which often exceeded the duration of the project! Not only was this annoying for the researcher and harmful to innovation, but such actions also invariably resulted in considerable wastage of public funds. Fortunately, this situation has witnessed considerable improvement over the years, and research environments in India are not as stifling as they used to be in the past. However, there exists considerable room for improvement for India's research fraternity to realize its full innovative capacities.

Furthermore, the unimaginativeness of the Indian technical workforce can be largely attributed to the rather outdated technical education system, whose evolution has regrettably stagnated over the years. Another concomitant event – the massive exodus of India's best and brightest science and engineering students to the seemingly greener pastures of the financial sector is a dagger to the heart of Indian innovation. There could be a chicken-and-egg dilemma at play here – an ill-equipped technical education system unable to motivate students whose lack of interest and unwillingness to persist with the profession in turn deflates the enthusiasm of academicians to mend an outdated system. Some readers might argue that this prognosis is rather harsh – after all, the Indian middle class is bourgeoning in both, size and purchasing power. Howsoever optimistic and patriotic one might be, there is little denying that an overwhelming majority of Indian economic successes of the past decade have been limited to improving foreign processes that infinitesimally, if at all, add to the quality of life of most Indians, especially the rural populations. The phenomenon of the bourgeoning middle class with increasing purchasing power is all but a result of rampant globalization.

The university as an economic engine

The conspicuous absence of product innovation in India will ultimately be detrimental to her development aspirations. The Indian Patents Act of 1970 was inordinately lenient and Indian companies soon realized that they could alter the manufacturing process of foreign corporations with little or no legal repercussions, thus producing these foreign products at significantly cheaper rates. Consequently, the attitude of Indian companies to research and development alarmingly regressed, and meagre, if any, amounts were allotted for new product development. As time progressed, this perilous situation witnessed no change as such 'copy cat' companies found a sizable share of votaries who believed that India could ill-afford spending money on research and development while a majority of its population was distressed with meagre incomes and poor standards of living. This approach unwittingly killed the spirit of innovation. Moreover, an overwhelming majority of Indians experience low standards of living compared to their counterparts in the developed world, and nearly a third live in abject poverty. The lowered purchasing power therefore has directly diluted demands for greater quality and consequently, has silenced one of the principal catalysts for product innovation – consumer need. Thus, besides being technically incapable of product innovation, Indian companies are relatively unpressured to innovate and develop newer and better products. For instance, there exists no Indian company that produces quality cellular phones for which a market of almost half a billion exists! The drought of affordable goods and services with exceptionally high quality, in turn, does little to improve the standard of living of the people, thereby completing a vicious circle. Faced with these facts, our excitement at India's adoption of new intellectual property rights policies is understandable and it is hoped that these new measures will go a long way towards improving the Indian Patents Act.

Given their profit-making whims, Indian companies will be hesitant to change their *status quo*. Any serious push for product innovation must originate from India's universities and academic institutions. By fostering an innovative spirit and training students to pursue bold and novel challenges that tread the frontiers of possibility, Indian universities could make a small aperture on the gates of innovation that, in time, given innovation's propensity for exponential growth, will ultimately open the floodgates and enable India to usher in a new wave of meaningful development. Imagine the change a small team of 'techno-entrepreneurs' can effect by simply targeting a market that is otherwise resistant to innovation. The sound application of technical knowledge could engender a product that is cheaper and superior to the one offered by the incumbents, thereby forcing the competition to innovate to improve their products or succumb to market forces. It is this never-ending sequence of innovation to compete, when executed across multiple markets, that ultimately improves the standard of living in a nation. This process – which could be referred to as Darwinian capitalism – has been one of the primary drivers of the American economy and confirms the central status of product innovation in national development.

Indian universities should aim to emulate universities in the United States and metamorphose into what Susan Hockfield, President of the celebrated Massachusetts Institute of Technology (MIT), terms 'magnets for creative businesses'[4]. America's universities have played a seminal role in fuelling the American economy, and Silicon Valley and the biotechnology hubs in Massachusetts and California all owe their origins and success to university-based research programmes. MIT graduates alone have originated technologies that have generated worldwide revenues nearing US$ 2 trillion[5], and when one considers that the United States houses as many as half of the top 20 universities in engineering and technology[6], the United States' rapid ascent and domination of the global order is as unsurprising as it is emphatic.

Science and technology and the new political dynamic

National policies are predominantly shaped by the availability (or lack) of technology and the largely uniform standards of living and low levels of public dissidence in countries of the developed world can be ascribed to the technological convergence of these nations. Once universities become economic institutions that drive progress, as they are in the United States, the tasks facing government become significantly tractable[2]. In such a situation, one of the overarching aims of a government would simply be the judicious allocation of resources for scientific research and extending support to organizations involved with the commercialization of potentially useful technologies. In the utopic event of universally healthy foreign relations, a relatively uneventful domestic landscape and the absence of war, science and technology policy would constitute the lion's share of a policy maker's duties. In any case, much of the politicians' energies would be directed at prioritizing research goals and enacting laws that are favourable for the scientific and technical communities of the nation as opposed to the present scenario wherein, due to the absence of strong innovation systems, politicians spend more time justifying the poor performances of some of their ill-equipped reforms to preserve the support of their constituencies and retain their posts. This could explain why election campaigns in developed nations such as the United States, in the absence of war, are largely centred on issues that would be considered peripheral in developing nations.

In the evolution of nations, a stage ultimately arises whereat national policies are aligned to maximize the benefits of technology. For India to attain this position and move away from the present model of vote bank politics, it is imperative that the Government of India reconstitutes India's innovation systems. In this regard, Indians owe a massive debt of gratitude to their first prime minister, Pandit Jawaharlal Nehru. His visionary leadership sowed the seeds of the Indian Institutes of Technology (IIT), whose graduates are widely regarded as one of India's best exports and among the best in the technological world. Nehru opined that 'India could only liberate herself from the clutches of poverty, bigotry, superstition and ignorance by the extensive and humane application of science and technology and spread of industrialization'. His views on the transformative powers of science and technology are best illustrated by his rather prophetic observation – 'Politics and religion are obsolete. The time has come for science and spirituality'. For all their systemic flaws, the Indian Institutes of Technology still produce a sizeable number of highly qualified scientists and engineers who repeatedly bolster the Indian economy. One can only imagine the possibilities if these institutes are restructured to realize their full innovative capabilities.

The secret of America's success

The earlier emphasis on restructuring the Indian technical education system specifically along the lines of the American system and not any other model seems striking. It is also deliberate and quite contrary to what the reader might assume – independent of the statistic that as many as half of the top 20 universities for engineering and technology are American. The statistic is merely an artifact of our strong corroboration of the American higher education system. In his famous study contrasting the structure of American and European universities specializing in science and engineering[7], Nathan Rosenberg made several excellent observations about how American universities displaced their European counterparts as the leading centres of learning and innovation as the 20th century gradually progressed. In fact, the rise of American universities to positions of preeminence is only as recent as the outbreak of World War II[2,7]. Many of America's leading universities, with a few exceptions, were only founded during the course of the 19th century, at a time when several of Europe's elite institutions were already centuries-old. At the advent of the 20th century, American universities significantly trailed the famed universities of Germany, Britain, France and Italy, and, in fact, most Americans intending to advance their technical education would do so in Europe. This trend has almost entirely been reversed today with American universities being the preferred destinations for higher technical education for students from all over the world.

At the very outset, American universities – perhaps due to visionary planning, pure circumstance or just plain aversion to all things European – broke away from the traditionally-accepted, European definition of a university. Then, in Europe, a university was considered to be an ivory tower and the university community largely comprised members of the elite class. Europe's industries, much like factories in the modern developing world, employed workers and labourers, called tradesmen, possessing highly specialized skills that they would generally acquire through apprenticeships. As a consequence, European industries were largely non-reliant on the universities for technology or personnel, and innovation was purely process-centric. Unsurprisingly, living conditions of the majority of the populace rivalled those in developing countries today.

Given that European society was feudal for much of its existence and that the university community was distinctly elitist, European universities gradually evolved to be controlled by members of the ruling class and later in the 19th century, by government. Thus, nearly all European universities became publicly-funded organizations and interestingly, academic and research staff at universities came to be viewed as civil servants. Subsequently, salaries were decided by government, and performance-based incentives were distinctly marginal. Students paid highly subsidized, or at times, no tuition fees and this drained the accountability of the university to its students. Education came to be viewed as a privilege that had to be gratefully accepted, and universities became largely unconcerned about the performance and employability of their students. On the research front, grants were centrally allocated to universities as lump-sums to be subsequently distributed to their various departments. This created a very peculiar situation wherein all research projects were prioritized equally, resulting in several resource-intensive endeavours encountering cash shortfalls and some projects receiving excess (and unnecessary) funding that, given the whims of bureaucracy, was always imprudently used up rather than being forfeited. Moreover, largely unchanging and uniform salaries for faculty, irrespective of their performance, precipitated a largely unproductive research environment. Consequently, European innovation evolved to become university-independent and was generally confined to prestigious federal laboratories uninvolved with education. In Europe, over time, as sources of innovation moved away from the university, the pool of innovators also shrunk. The surpassing of such an extra-university innovation model by a more university-centric was imminent.

In contrast, most of America's leading research-intensive universities are private, and even public universities are largely unshackled from government. This frees universities from the wrangles of bureaucracy and makes them more responsive to economic conditions than state-controlled organizations. American universities are and have always been veritable corporations offering a highly valued service and students are viewed as paying customers. Just as it is in the best interests of a corporation to be ever-mindful of changing customer needs and desires and continually introduce product innovations to sate these demands, American universities too have consistently upgraded their curricula and research programmes to address the needs of their students and stakeholders. If a university refrained from such constructive practices, students would simply not enrol in such an institute and instead opt to join a university that they perceived was offering a higher quality and more employable education. In some cases, the needs of the local industry prompted educational institutes to introduce altogether new programmes to attract students with the lure of employment in these soon-to-burgeon industries. A notable example is the emergence of chemical engineering as an academic discipline at MIT. Additionally, government constituted one of the largest users of university-derived research. High student application and intake rates translated to greater income for the universities, which could then be utilized towards improving research infrastructure and elevating faculty salaries. At the faculty level, Darwinian competition for tenure and funding was strictly enforced and prolific faculty members conducting pioneering research that enhanced the reputation of the university were duly awarded. After all, in an education system such as this, a university's reputation in society and amongst students would unsurprisingly be its most potent marketing instrument and its faculty would undoubtedly constitute one of the arms of this marketing machinery (with its sports teams being another that comes to mind). Moreover, Darwinian competition at the faculty level also sowed the seeds of healthy competition within and between academic departments, thereby sustaining a highly productive research environment.

Evolution of the American social order

One might question why industries in Europe and the United States viewed the role of the university so differently? After all, some of the largest benefactors of most American universities have been entrepreneurs and industrialists. This distinction becomes all the more glaring when one realizes that American and European industries would produce essentially the same type of products. The unique social conditions that prevailed in the nascent United States and their extreme aversion to the rigid social class structure of their European ancestors played a primary role. The American aspiration for egalitarianism and autonomy created a unique sense of capability and achievement in its populace that suggested that one could acquire one's status in society by acquiring the relevant skills. If one could not acquire these skills, one could engage the services of others possessing these skills and reward them handsomely for their efforts. Everyone was free to pursue his or her own economic destiny and free market capitalism emerged at every level. Thus, entrepreneurs, in order to sustain their competitive advantage, would evidently invest heavily in centres with the highest concentration, and by extension, greatest likelihood of scouting highly skilled workers and such centres are almost always universities. The dynamic social order germinated healthy social competition and it was in the entrepreneur's best interests to sustain innovation. This also explains why university-based entrepreneurship is rife in the United States. On the other hand, in Europe, only members of the elite class were free to engage in entrepreneurial activities and members of the working class had little or no opportunity to improve their social status. Thus, they had no option but to continue working for pittances while their employers continued to reap the fruits of their toil. The relatively static social order diminished the value of technical education in the eyes of the working class and created a sense of complacency among the elitist, consequently diminishing the reputation of the university as an engine of economic progress.

The university as an economic engine and why it particularly applies to India

Some might question the validity of these observations, especially the applicability of the American example to the Indian context. After all, rural India, which accounts for nearly three-fourths of India's population[8], is far detached from the economic engine of Silicon Valley. They might conclude that it is not the structure of the university system but, in fact, the number of universities and educational institutes that is vital to India's development. 'How can a university in an urban area that can, at best, enrol only a few thousand students improve the lives of the rural population in India?' is their contention. Many Indian politicians agree with this view and they too believe that lack of access to technical education is the root cause of all of India's ills. In response to this perception, the Indian government recently embarked on an ambitious project to increase the number of IITs from 7 to 15 as well as establish more medical research institutes along the lines of the prestigious All India Institute of Medical Sciences (AIIMS). That these centres have been established in urban areas has yet to strike many! Wasn't the lack of centres imparting technical education to rural India one of the raisons d'être for these institutions? Besides, establishing universities in rural India will not alleviate any problems. If anything, as shall be presented later, they could add to India's woes. India's ails do not stem from a lack of technically 'qualified' professionals. Each year, Indian universities yield over 650,000 engineers[9]. This immense group of technical professionals that perennially grows with each passing year, by application of Lotka's inverse square law of population productivity, should be able to address the problems of rural India through the technologies and solutions they conceive. That this has yet to occur reveals a disturbing reality – India's problems do not stem from a shortfall of technical professionals, it is the lack of quality of these professionals that afflicts the nation.

The lamentable state of technical education in India

India's turbulent history prior to independence and its ensuing maturation as a stable, secular, egalitarian and democratic republic are analogous to the evolution of the American social order. Having liberated herself from the discriminatory and exploitative rule of the British, India's unique modelling of her social institutions is akin to that of the United States, and India's recent successes could be ascribed to the dynamism of these institutions. However, the one aspect that has somewhat regrettably lagged has been the restructuring of the university system. Nearly all of India's most prestigious centres of learning are state-sponsored and nearly all, including many of the prestigious IITs and the Indian Institutes of Management (IIMs) are modelled along the lines of European, notably British, universities. Consequently, dogmatic bureaucracy and conditions that stifle innovation have percolated into most of the Indian universities and this has all but killed original research in most departments. Barring a few exceptions, these universities have slowly degenerated into lecture halls where instructors merely impart outdated knowledge to students.

India is also home to a slew of engineering colleges that are administered by private trusts and societies but the vast majority of these institutes are light years apart from the private universities of the United States. One could define these colleges as poorly managed corporations offering an inferior product that the customer is forced to buy because it is the only product in that particular geographical market. When viewed in this light, it comes as no surprise that the vast majority of Indian engineering and technology graduates are considered unemployable by leading technology firms[10], student interest in science and engineering has alarmingly receded and the demand for conceptually static professions such as finance and banking has increased. When Lord Keynes quipped that education was the inculcation of the incomprehensible by the incompetent into the indifferent, he was probably referring to the technical education system of India. When faced with this uncomfortable fact, Indian academicians and politicians point to the success of alumni of the IITs and IIMs in the demanding environments of Silicon Valley and anoint the existing technical education system as being one of the best in the world. It is high time they realize that the IITs are only a small part of the technical education system, not the whole; and that most successful IIT alumni honed their skills at American universities.

The numbers' game

Based on the Indian government's recent efforts to establish several more institutions akin to the IITs, one could conclude that awareness of the strong correlation between the strength of a nation's technical workforce and its economic success has finally caught on with India's administrators. However, their conclusion that India's science and engineering capabilities could be markedly augmentted by establishing more institutions imparting technical education seems worryingly misplaced on several counts. As was mentioned earlier, the problem is not one of quantity, but quality and a quick glance at India's recently released federal budget[11] leads one to assume that these new institutions would simply assimilate and propagate the flaws of the older, seemingly unhealthy universities in whose likeness they will be modelled. We fear that such an exercise could potentially consign India as being a destination with more unemployable engineers and scientists than any other country, and these fears assume darker shades when one considers that such institutes threaten to siphon away federal funding from vital social institutions and services against which they directly compete. It could have several undesirable ramifications on the standard of living in India. Indeed, the Indian government's adopted methodology seems more applicable to nations whose citizens have a more respectable minimum standard of living.

Another pertinent and oft-overlooked aspect is the concurrent expansion of the job market for engineers and scientists. An increase in the number of universities offering technical degrees, irrespective of the quality of the education that they impart, will increase the number of job applicants and, though desirable from an employer's perspective, if the number of available jobs for technical professionals does not see a commensurate rise, India might find itself housing a great number of technical professionals performing non-technical job functions. Such a development not only reduces the economic returns of a technical degree and lowers the standard of living of technical professionals, but also negatively impacts accountability, consequently drastically impairing the innovation capacity of the nation.

A closer inspection of the education system of the United States in its totality and contrasting it with India's reveals some interesting insights on American societal engineering and how India should go about restructuring her own education system. At the outset, Americans have universal access to primary education and enrolment for primary education is nearly 100%, whereas enrolment ratios for secondary and tertiary education were as high as 94% and 82% respectively in 2006 (ref. 12). Importantly, the enrolment ratio for science and engineering programmes was about 15.6% and the enrolment ratio for science alone was about 9% (ref. 12). In comparison, South Korea, an emerging economic powerhouse and a nation that only recently restructured its own education system, also grants her citizens nearly universal access to primary education. The enrolment ratios for secondary education, tertiary education, science and engineering and science alone in 2006 were 94%, 91%, 37.5% and 9% respectively[12]. The peculiarly high enrolment ratio in engineering programmes is an artifact of the *chebol*-based economy of South Korea and the dominant position held by South Korean *chebols* in the global materials and electronics markets. Thus, the abnormally high concentration of engineering degree holders can be and is easily accommodated by the Korean economy, something that the Indian government, as was alluded to earlier, will need to pay greater attention to.

Most would concur that the success of a nation largely rests on the efficacy of its social services and civic infrastructure, and that these systems being severely strained in India places a cap on the attainable standard of living of Indians. The aforementioned education statistics for the United States and South Korea reveal that a vast majority of their citizens have, at the very least, received some form of secondary education, and a large proportion of the population has at least one tertiary degree. Thus, America, South Korea and, evidently, nearly all other industrialized nations rank as some of the most educated societies in the world. The fundamental difference between industrialized western democracies and those nations that have only recently witnessed industrialization is the difficulty of the curricula at the primary and secondary levels. An intuitive conclusion is that the greater demand for science and particularly engineering programmes in newly industrialized nations such as South Korea, Taiwan and Singapore has forced the authorities in these countries to elevate the difficulty of pre-university programmes in order to curb the number of students pursuing technical degrees.

Nonetheless, in nations such as the United States, Canada and countries of Western Europe, one of the major goals of the primary education curriculum is to emphasize civic responsibility, whereas the secondary school curriculum functions more as a transition between civic and professional education. The basic secondary school curriculum only provides students with essential analytical, interpersonal and trade skills, whereas specialized subjects catered to stimulate interest or prepare students for a particular professional programme are included in the curriculum only as electives. The American education system is 'unbiased' and influenced by the unique structure of the American economy that necessitates an ample supply of qualified technical and non-technical personnel. Thus, with a majority of her citizens having at least a secondary degree, civic consciousness in America ranks as one of the highest in the world, most Americans understand the processes and variables that influence their standard of living, and nearly all are aware of their social obligations. It translates to wholesomely better living conditions and improves functioning of American civic services as well as the government owing to higher tax payment and informed political participation by the people. The same also holds true for other industrialized nations and could explain why the standard of living in several of these nations are nearly uniform despite them trailing America in innovation and research. America's greater technological prowess merely accelerated her ascent in the world order and the globalized nature of American corporations helped spread the benefits of American innovation to other nations whose citizens were in a position to afford these services.

Most Indians, in comparison, did not have access to universal primary education until recently and the gross secondary and tertiary enrolment ratios in 2006 were only 54% and 12% respectively[12]. Of those enrolled in tertiary programmes, the science and engineering enrolment ratio was about 20.3% whereas the enrolment ratio for science alone was 14.3% (ref. 12). Contrasting these statistics with those from America raises several alarms. Firstly, very few Indians have secondary education and still fewer have a university degree. Alternatively stated, the number of Indians presently pursuing higher education is a drop compared to the ocean of Indians who do not even receive secondary education, and with 119 researchers, per million of population, notwithstanding the quality of their research, India has one of the lowest R&D density in the G8 and BRIC (Brazil, Russia, India, China) nations[12]. In comparison, America's R&D density of 4628 researchers per million of population suitably justifies her higher innovative capabilities.

Making India more competitive

Some readers might find the citation of India's R&D density of just 119 per million of population and the previously outlined objection to the establishment of more institutions such as the IITs as paradoxical. However, it is felt that such an argument, though justified and perhaps applicable to nations with significantly better standards of living, is largely inadmissible to the Indian debate. A vastly different route is required to improve the innovativeness in science and engineering and more funds should be allocated towards improving primary, secondary and vocational education in the nation and elevating the cognizance and civic sense of the populace. Thus, while directly improving the civic infrastructure of the country, this strategy also enables people to become more cognizant and raises the perceptibility and creativity in society. A population unshackled from the largely chaotic protocols of an unorganized social system will inadvertently spend their time more creatively and that children raised in such 'rational' societies are more likely to be 'rational' themselves.

According to the 2001 census[13], nearly 330 million Indians were aged under 15 and accordingly, eligible for primary education, whereas 66 million and 154 million Indians were eligible for secondary education (ages 16–18) and tertiary education (ages 19–24) respectively. In 2006 (ref. 11), the Indian government allocated nearly Rs 127 billion for primary education programmes in the nation, while secondary and tertiary education both received about Rs 58 billion, with tertiary education receiving an overwhelming share of this allowance. In comparison, in 2010, the government has set aside about Rs 150 billion for its flagship primary education programme and Rs 17 billion for middle-school education. Commensurate to the increase in funding to the government's flagship universal primary education programme from Rs 110 billion in 2006 to Rs 150 billion in 2010, funding for nutritional programmes at primary schools, a necessary and vital aspect of primary schooling, also rose from Rs 30 billion to Rs 95 billion in the same four-year span. In 2006, special rural education programmes received about Rs 6 billion whereas girls' and women's education programmes received about Rs 2.5 billion. Vocational education directly received only about Rs 180 million. While figures for 2010 were yet to be finalized by the time of publication of this article, vocational training and skills education for adults were allotted about Rs 370 million and Rs 10.5 billion respectively. These increases are quite heartening and indicate the government's realization and appreciation of the importance of primary and vocational education. However, despite the sizable increases, these figures, especially those for primary education appear paltry even on the best of days, and the Indian government ought to spend more than 0.3% of the nation's GDP on a group that constitutes over half of its population. Encouragingly, recent evidence suggests that these discrepancies are on the mend.

Similarly, the 2006 budget allocated about Rs 19.27 billion to the University Grants Commission (UGC), Rs 6.3 billion to all the 7 IITs, Rs 2.76 billion to the 18 National Institute of Technologies (NITs), Rs 615 million to the 6 IIMs, and Rs 1.11 billion to the Indian Institute of Science (IISc). The All India Council for Technical Education (AICTE) received about Rs 1 billion and a host of smaller, centrally administered engineering institutes received roughly Rs 100 million each. Funding to these institutions was greatly increased in the just-released 2010 budget, with the UGC set to receive Rs 43 billion, the existent IITs all receiving Rs 7.74 billion, the new IITs allocated about Rs 4 billion, the NITs getting Rs 8.10 billion, the IIMs receiving Rs 748 million and the IISc receiving Rs 800 million. In fact, there is a possibility that these numbers could swell further, with some bodies positioned to receive as much as twice their original allotments. However, like primary education, these rises in funding for tertiary and higher education ought to be assessed with a dose of caution. Of the 154 million youth eligible for tertiary education, only 20 million or so actually enroll in a university, an overwhelming majority of which reside in the cities. Of these institutions, only IISc ranks as a genuine research-intensive institute and perhaps the only basic sciences (well-established deemed) university to receive any sizeable funding from the government. Of the total number of students enrolled in science and engineering programmes at Indian universities, roughly three quarters pursue basic science. However, funding for applied science education significantly dwarfs the funding to basic science education and rather distressingly, funding for the basic sciences, on evidence of funding to the IISc between 2006 and 2010, has shrunk. Many would agree that despite being perceived as being more socially relevant, the benefits of applied science research do not exceed those realized by basic science research and a great determinant of the success of America's research programmes has been its equal prioritization of both basic and applied research. While the government specifically set aside as much as Rs 7 billion in 2006 for emerging areas of research such as nanotechnology and pharmaceutical research (2010 figures unavailable), how much of this actually gets allocated to basic scientific research as well as the finer details of the funding process are still nebulous.

The statistics presented earlier reveal that while the government has unilaterally increased funding in education, technical education continues to find greater favour. Given the disparities in per capita investment in primary and vocational education on one hand and tertiary education on the other, it is imperative that India correct this skew if it intends to improve the dismal standard of living of its citizens. While it is true that tertiary education will continue to command a bulk of the investment in education, the government must divert considerably greater funds to primary and vocational education, and steps to achieve this transition have been described in the remainder of this section.

As a first step, it would be prudent for the government to reformulate the education budget to support four principal initiatives – establishment of a national need-based university scholarship scheme capable of supporting no fewer than 50 million students, instituting a national library and book bank scheme primarily geared towards primary education that provides books and education materials to children from rural and impoverished backgrounds at no cost, establishment of community vocational training centres to cater to the needs of the large adult and teenage population that could not avail of formal education, and lastly, establishing an organization similar to the National Institutes of Health (NIH) and National Science Foundation (NSF) of the United States that oversees funding of research projects[2].

Encouragingly, several items in the federal budgets address related areas. However, the peculiar practice of fragmenting core schemes into smaller projects of limited scope to be grouped under different categories and operated by different agencies has pointlessly added to the operational expenses footed by the government. We believe consolidating items such as girls' and women's education with primary education could greatly improve the operational economies of scale of such schemes, eliminate several bureaucratic costs and make the education budget more malleable to the population's needs.

It is absolutely essential for the Government of India to extend significantly greater support to primary education. Accordingly, the Indian government's policy of establishing more primary schools imparting free and mandatory education in the villages of India is very heartening. Primary schooling, as was mentioned previously, will enhance civic responsibility and one hopes that topics such as abidance and respect of the law, personal and community hygiene, and payment of income tax will be emphasized instead of the apathetic curricula in place in many schools across India. The Right to Education bill which the current government has passed recently is a laudable achievement.

According to the 2010 budget, the government has also allotted nearly Rs 25 billion for scholarships to students from marginalized groups for post-matriculate education[12]. This is a welcome move. The government should now place girls' and women's education as one of its top priorities and considerable funds should be directed to realize free girl's and women's education at all levels. After all, an educated female population is one of the most effective ways to increase education levels in the population as well as curb population growth. India's historically low education rates and high population growth is a direct consequence of untoward suppression of female education programmes by vested interests in Indian society. A quick comparison between the federal budgets from 2006 and 2010 reveals that the government has indeed injected huge amounts to correct these disparities and it is highly commendable. Several schemes have also been justifiably introduced to benefit religious minorities and members of the socially disadvantaged communities. Women's higher education must be viewed and supported generously. If the Government of India makes women's education free up to graduation, and perhaps give handsome fellowships to all women desiring to pursue postgraduate studies, in excess of 50% of the population will immediately benefit from this scheme. An educated mother means a lot. The marriageable age is automatically increased and thus there is indirect population control. No educated mother would like her off-spring to be less educated or a law-breaker. The statistics about both parents being graduates, irrespective of their caste, creed or religion, will certainly endorse this view and demonstrate that they do not have more than one or two children, who also go on to take tertiary education, This expenditure will have far-reaching consequence. Additionally, it would also be desirable if the government works with universities and community colleges to include more vocational training programmes in their offerings and recast existing adult education schemes as vocational education schemes. This aspect shall be discussed in greater detail in later sections.

Several perplexing items remain an integral part of the budget and the government ought to remedy some of these schemes to further improve the focus of the budget to conform to the four domains outlined above. Special rural education programmes generally receive about Rs 6 billion each year whereas girls' and women's education programmes received about Rs 2.5 billion in 2006 (2010 data unavailable). However, quite puzzlingly, education programmes and schools for children of government employees were awarded about Rs 7.8 billion in 2006 and as much as Rs 20 billion in 2010. Although provisions for employees of the Indian government are laudable, they seem inordinately excessive when one considers the low allowances for rural and girls' education. There are several reasons why such an excessive annual allowance for children of government employees is not justifiable. Firstly, most rural areas in India do not have actual physical spaces for schools, consequently necessitating enormous expenditure on infrastructure development. On the other hand, schools attended by children of government employees are in urbanized areas and are quite well-equipped (in fact, these schools rank as some of the most prestigious in the nation and offer educational programmes and fees which only the elite can afford). Additionally, most rural families cannot afford sending their children to school whereas most urban families spend considerable amounts on their children's education. These factors, along with several more, make the government's motives for ranking improvement of schools that already are some of the best in the country alongside schools with no physical spaces and attended by children from underprivileged families seem rather queer. Another interesting item in the federal budget was the allocation of about Rs 174 million in 2006 and Rs 390 million for education programmes for children of Tibetan refugees. It is definitely a good idea. Assuming the naturalization of Tibetans into Indian society is nearly complete and the Tibetan subpopulation exhibits similar statistics to India's, each Tibetan child stands to receive about Rs 5000 each year for education – considerably greater than the average Indian child. This statistic has somehow escaped the attention of Indian sociologists and demographers. In order to build a strong homogenized nation, all children should receive the same privileges irrespective of their ethnicity, language or religion.

Understandably, these budget modifications will siphon away significant funding from technical education to primary education, and accordingly, universities will have to either suitably redesign their curricula and restructure themselves to not only cope with this funding 'shortfall' or the government should also allocate more funds to improve quality. A plethora of alternatives exist to achieve this seemingly difficult task and the following sections will delineate some of these measures.

The case of chemical engineering: a demonstrative example

So how does one go about correcting this undesirable situation that India and Indian universities find themselves in? As was mentioned earlier, a bulk of the blame for the current state of technical education in India rests on the indecisiveness and myopia on the part of those administering India's universities. Indian politicians too have a role to play in this overhaul of the Indian technical education system. One key observation in the previous assessment of American universities is that most of these institutions are private and autonomous. Consequently, we feel it would be better to grade state-funded universities using yardsticks of excellence such as impact factors, citations, *h*-indices or other similar metrics, and commensurately grant them greater autonomy to decide and possibly raise tuition fees. It is hoped that the national need-based scholarship programme will adequately complement this fee hike. However, we do not recommend *in toto* privatization of universities as it would not necessarily translate to better education standards – India's private engineering colleges and private universities are testament to this. In fact, the non-compliance of these institutes to stipulated academic standards, their indiscrete levying capitation fees and the dearth of qualified faculty in their ranks has left the government admittedly queasy about privatization of educational institutes. Achieving privatization without sacrificing academic standards or affordability is now a moot question for the authorities.

In lieu of our familiarity with the chemical engineering curricula and research programmes in place at most of India's leading centres of chemical engineering education, all suggestions presented hereinafter have been formulated using chemical engineering education as a demonstrative case. However, considering the unique competencies of chemical engineering as both, a scientific and engineering discipline, and its vast array of applications, we are confident that these suggestions will be pertinent to nearly all technical disciplines. To the uninitiated, chemical engineering is arguably the most versatile of all engineering disciplines and incorporates concepts that encompass the entire gamut of science and technology. Tersely, chemical engineering is the engineering of chemical and biological systems that vary considerably in their size and complexity and could either be products, the processes that make them or applications pertaining to the use of these products[14,15]. Chemical engineering predominantly involves the astute and ingenious application of basic scientific principles to achieve practical, socially relevant outcomes. Evidently, chemical engineering spans a very broad range of interests and activities and is central to many applications in energy, agriculture, food, healthcare, environmental protection and remediation, defence, transportation and communication. The chemical industry – a manifestation of chemical engineering practice – is one of the largest employers in the world (it contributes nearly $400 billion in goods and services to the American economy[15] and modernization of the industry via a pursuit of excellence in research and academia offers the possibility of considerable national development). After all, many of the problems that were stated before – food shortages, environmental destruction, lack of clean water, rampant spread of epidemics and declining energy reserves fall within the purview of chemical engineering.

It is this broad range of interests that sometimes discombobulates formulators of chemical engineering curricula. Not only do they have to remain 'loyal to their roots', they also feel pressurized to accommodate courses in emerging fields such as biotechnology, green chemistry and engineering, and nanotechnology, all the while ensuring that the entire programme, like all other professional degree programmes, is limited to 4 years. It is a tough task for the best of minds, let alone most administrators at several of India's engineering colleges. Already, chemical engineering curricula include multiple courses in chemistry, biology and physics, a plethora of courses in basic and applied mathematics, and courses instructing students in the core competencies of the profession – transport phenomena, thermodynamics, reaction engineering, chemical synthesis and process engineering. Any more courses and students, already disenchanted with engineering, would be further discouraged to enrol in chemical engineering. After all, salaries for a freshly graduated Indian chemical engineer and a computer analyst are not markedly different and students could, somewhat justifiably, construe the extra effort required to attain a chemical engineering degree as unnecessary and unrewarding. However, biotechnology and nanotechnology, if they already have not, will soon assume central roles in several chemical applications and failure to introduce students to these subjects would be foolish, if not criminal.

A natural and often popular course of action is to demarcate a burgeoning and imminently gauche curriculum into separate disciplines, each focussing on a distinct subdomain, for instance, demarcating chemical engineering into perhaps industrial engineering and biotechnology or chemistry into biochemistry and abiotic chemistry. In our opinion, this action – referred to as 'over-specialization' in some circles – though seemingly rational, could precipitate some undesirable ramifications, especially in emerging economies such as India. One glaring problem that comes to mind is the unpreparedness of graduates to deal with the cyclical nature of an economy – what do petroleum engineers do when the oil markets become more vagarious than ever? Also, and more pertinently for chemical engineering, stripping down a discipline to subdomains erodes appreciation for the system that is 'greater than the sum of its parts'. In fact, at a time when most disciplines are experiencing a convergence of goals, and the traditional boundaries between them are become fuzzier, merging disciplines under the banner of knowledge that they seek to extend or apply seems more rational. However, it is not recommended. The present university structure has proven to be quite adroit at addressing some of society's problems and diverting away from this model could prove onerous, especially for nations such as India.

Redesigning curricula

Universities in America have addressed the problem of curriculum accommodation by reducing the core requirements for a chemical engineering undergraduate degree to only include few courses in chemistry, physics, biology, basic and applied mathematics, transport phenomena, thermodynamics and reaction engineering. The core course load has literally shrunk by as much as a quarter, if not more. Instead, a great degree of flexibility is built into the curriculum by offering several electives in the more peripheral aspects of the discipline and these electives are generally instructed by faculty members whose research interests lie in that subject. Significantly, undergraduate research is included as a recommended, if not mandatory requirement and students are encouraged to work under the auspices of a faculty member, conducting research and indulging in practical learning of concepts that interest them. Conversely, some other universities achieve the same goal by urging their students to embark on mandatory internships in industry. Thus, students develop highly specialized and valued professional and analytical skills which immensely aid them and their employers in their later careers. For the faculty members and companies, undergraduates constitute a pool of future graduate researchers and employees respectively.

This model understandably necessitates the existence of active research programmes in a university – a phenomenon that is hitherto absent in most Indian universities. Unfortunately for students and all stakeholders of chemical engineering in India, several programmes in the country have attempted to wantonly replicate this American model, and owing to the absence of active research programmes, have unsurprisingly deteriorated to the point of lament. The fault lies in the university administration's mistaken prioritization of restructuring the undergraduate curriculum over development of effective research programmes. Whereas the undergraduate curriculum needs to be restructured to make it more pertinent and appealing to the students, such a change cannot be successfully sustained in the absence of internationally acknowledged faculty members. It should be pointed out that those

Indian universities that have been fortunate to host faculty members of international repute and maintain highly competitive undergraduate programmes as a consequence should consider remodelling their undergraduate curricula along American lines. For those institutes attempting to build their faculties and research portfolios, it is suggested that the curriculum be temporarily designed to include most of the courses in chemistry, physics, biology, mathematics and the core competencies of chemical engineering while sacrificing a few humanities electives in favour of additional subjects such as biotechnology and nanotechnology. Some might question the logic of sacrificing humanities electives and potentially argue that the absence of such courses would be detrimental to the development of 'soft' professional skills. In our opinion, the poor development of soft skills does not afflict the Indian chemical engineer. It is the poor development of their engineering skills that affects them. However, inclusion of an ethics course is strongly recommended. It would not only instruct students in aspects such as law and professional morals, but could also imbibe a greater sense of social and national accountability in the minds of the students.

Another aspect that we would like to emphasize – and one that is particularly pertinent to chemical engineering education – is the use of demonstration experiments and laboratories to complement classroom instruction, especially for industrially relevant subjects. It is our belief that inclusion of demonstrations in the curriculum is akin to some of the practical research experiences and internships that were mentioned earlier, albeit to a lesser extent. Closer collaboration between government and universities to formulate and offer several vocational training programmes – often referred to as diploma programmes was proposed earlier. Engineering departments are best placed to achieve this goal and are encouraged to model their diploma programmes along the lines of those offered at community colleges in North America. In fact, offering diploma education programmes in engineering technologies not only achieves the goal of establishing excellent demonstration and practical training facilities, but also increases the employment opportunities for individuals previously unable to pursue tertiary education owing to a lack of prior education. It has a tremendously positive effect on the technical skill levels of the working population and could greatly aid in strengthening India's hitherto weak manufacturing sector. In fact, over time, some diploma programmes could possibly expand into full-fledged academic departments offering degrees catering to a particular industrial niche. For example, the Institute of Chemical Technology (ICT) in Mumbai remains one of the only institutions in India and possibly the world to offer specialized courses in fields such as dyes manufacturing, textile manufacturing and paint technologies, among several others, that specifically cater to the demands of the local industry.

Superannuation

The Indian government should seriously think on unilaterally and uniformly extending, if not completely doing away with retirement ages for qualified technical professionals, as is the case in the United States. This proposition might appear shocking and contrary to the general perception that people will continue to work until death and block the chances of youngsters. However, in light of the fact that this has still not happened in the US where professors retire much later than their Indian colleagues (in fact, since there is no retirement age, US-based professors actually retire 'early' to pursue other passions) extending the retirement age seems to be a viable strategy. With so many vacancies in even the best institutes, some of which will never be filled, no matter what schemes are adopted to lure professionals to join academia, the pay and perks given by industry in any economy will never be matched by academia and only those who truly appreciate teaching and research will take up appointments at universities. With the arrival of foreign universities and their proposed higher salaries, an exodus of talented faculty members from institutes such as the IITs, IIMs and reputed state universities is on the cards and retiring good professors would be greatly misguided. Occasionally, arguments are made that 'unwanted and self-promoting individuals' misuse this privilege to the detriment of the institute. To counter such developments, those past 65 or 70, barring a few exceptional individuals, should not be assigned administrative roles. This also ensures a steady influx of newer ideas and administrative styles.

Presently, retirement ages vary greatly from one state to another, and are also different for employees of the central government, consequently creating a 'second' class of academics within the same system – those based at elite, centrally funded institutes and ill-equipped state universities. There is a need to bring parity among all universities in this regard. The nation can never achieve greatness by ignoring the state universities that are largely subject to archaic practices and are at the mercy of myopic state machineries. These are particularly detrimental to growth and the superpower ambitions that India harbours.

The retirement age for faculty at private technical institutes in India is 70 – significantly higher than the nominal retirement age of 60 in most public institutes, particularly the state universities and institutes. Central universities, IITs, IISc and IISERs have been bestowed with the advantage of retirement age of 65 years whereas some of the best state universities and institutes are denied this privilege despite their stellar performance. Why does not the Central government make it mandatory for the states to adopt uniform policy in recruitment and retirement? Even the high profile TIFR does not enjoy this privilege despite it being a DAE-owned institute. One simply fails to understand this logic. Something is amiss in our policy, particularly the attitude of the state governments, and many have not even implemented the 6th Pay Commission salaries. How will the best talent remain in state universities and why should they? If the Centre is going to reward only institutes under its umbrella, we will never achieve excellence in science and technology. The best faculty from the state universities will eventually migrate to the greener pastures of the central universities and institutes. The human resource for research at these elite institutes ironically comes from poorly funded and ill-equipped state universities. Barring a few states where the retirement age is nominally increased to 62, all state universities have a retirement age of 60. Besides, the acute problem of recruitment of quality faculty is marred by the inordinate delays in filling up these posts; and the bureaucracy cripples the process by being insensitive to the demands and requirements of these universities, let alone creating excellence by attracting talent. Even a progressive state like Maharashtra has not raised the retirement age. The superannuation in all technical institutes must be uniform throughout the country and MHRD and S&T Ministry must take a lead in educating the states in this regard.

This disparity in the retirement ages assumes considerable significance in light of the abeyance of the pension scheme for government employees. Unsurprisingly, several distinguished professors and scientists from central research laboratories and institutions such as CSIR, DRDO, DAE, following their 'premature' retirement, have assumed positions at Western universities, particularly those in the United States, and have maintained their productivity. It is our conjecture that as research programmes at universities are gradually strengthened and their curricula evolve, extending the retirement age of qualified individuals who have been torchbearers for the profession will ensure that deficiencies in the education system are partly compensated by apprenticeship programmes that are common in industry. At universities, competent faculty nearing the end of their careers, meanwhile, should be appointed to assist, if not lead teaching and demonstrations. It must be seen to it that strict qualification requirements are enforced and only the meritorious be favoured. Critics might argue that such a scheme could enable individuals to perennially continue as professors, thereby possibly limiting the opportunities available to younger scientists. Some of such senior professors, who have continued to carry on are far more productive and age has not diminished their enthusiasm for high quality work. We believe such fears are misplaced and quite contrarily, there is a dearth of qualified faculty to meet the demand of universities. Understandably, during periods of economic turmoil, staff in the twilight of their careers, unless exceptional, should not get extensions of retirement, in favour of younger candidates who have yet to establish themselves socially. Such human resource practices are inherently flexible and will preserve a relatively healthy social order.

Building research competency

The government's decision to hurriedly institute eight additional IITs has also been criticized by many academics for its political undertones. There is no denying that that India needs several more branded institutes of higher learning which would be hubs of new knowledge, but a lack or even absence of proper planning, as seems to be the case with the establishment of these new IITs, will only be detriment to India and these institutes. Not only are most of these institutes poorly planned, but in lieu of the government's European approach to funding universities, every additional central university is a drain on precious resources. Consequently, funds that would otherwise be allocated for establishment of such institutes would be better utilized toward restitution of existing institutions across the nation, especially modernization of the curricula and teaching facilities. It would be better to identify performing institutes with a global standard across the nation and convert them into central universities or world class or innovation universities. Very recently the Ministry of Human Resources Development (MHRD) undertook an exercise of evaluating all deemed universities including IISc, TIFR, JNCASR and the like. Most of these are engineering and technological institutes. The conclusions speak volumes on the quality of education. Only 38 were accorded 'A' grade to be fit for the deemed university status. For instance, ICT is the only state-funded deemed university among the four in the State of Maharashtra to get the A grade; the others being centrally funded – TIFR, TISS and Central Institute of Fisheries Education. Except the salary grant, there is no other support including development grant received by the ICT from the State of Maharashtra. The UGC had sanctioned Rs 2.42 crores during the X Plan and about Rs 4.84 crores during the XI Plan. How can such a nationally important institute sustain excellence in this competitive world? Also, it is strongly recommended that India expand her pool of qualified faculty and germinate several reputed research groups prior to establishing new institutions. Formulating modern and pertinent instructional material is highly contingent on the competence of faculty at a university and as mentioned previously, undergraduate education in India suffers owing to the absence of strong research programmes at these institutes. As universities attempt to augment their research base, allocating more funds for maintaining extensive libraries, knowledge databases and interactive resources could greatly improve or sustain the quality of undergraduate education, preventing relapse. Barring a few exceptions, library collections at Indian universities are distressingly outdated and the library infrastructure is noticeably dilapidated. Additionally, the government must encourage universities to sign memorandums of understanding (MoUs) with prestigious American universities, and also European universities, to specifically avail of their undergraduate teaching resources and enable faculty at these institutes to spend adequately long sabbaticals primarily engaging in teaching, and possibly research, at Indian universities. Additionally, internationally renowned faculty members must be invited to serve as expert consultants on curriculum design and these individuals must be suitably rewarded for their services. Better still, these consultants could also be appointed as referees of research programmes. Most MoUs that have been struck between Indian and foreign universities have almost exclusively focused on research exchange programmes. These must be extended to encompass undergraduate education. The resources to achieve these changes exist and many within India's research fraternity would agree that while there is necessarily no dearth in funds allocated by the government for research and education (the 2009 federal budget allocated as much as Rs 284 billion for research and development, a 17% increase from the previous year, and higher education also received about Rs 132 billion[16]; the exact 2010 budget breakdown was not available at the time of publication of this article), the government's peculiar funding policies inadvertently amplify the damage that one unproductive institute could wreck. New institutes designed along conventional lines will imminently descend to unproductiveness.

Many Indian academicians are greatly encouraged by the government's recent initiatives to establish advanced research centres in clean energy, environmental engineering, defence and military technologies, biotechnology, nanotechnology and a host of other potentially important disciplines at some of India's universities. This will significantly bolster research at these universities. However, very little thought has been given to staffing these centres – a problem that, if left uncorrected, could deteriorate these centres to becoming resource drains. Thus, the tasks of developing productive research programmes at India's universities and staffing these advanced research centres with qualified scientists are congruent. In the recent past, India's universities have turned to the Indian scientific diaspora in North America and Europe and have attempted to cajole their services in building their research portfolios. Sadly, this endeavour has yielded mixed results. At the outset, few have responded to these offers and the majority of those that have returned have made excessive demands. One cannot fault these expatriates – they are staking largely equilibrated careers in highly productive and rewarding environments for positions in institutes with little or no research ethos, possibly reduced funds and a lack of personnel to realize their research aims. Thus, accountability has been replaced by expectations of indebtedness from the university – a scenario that is likelier to debilitate than reinforce a research programme. Additionally, several of such expatriate appointments are made through personal acquaintances, implying that merit is not necessarily the determining factor behind several of these appointments.

Staffing India's universities and research institutions with qualified personnel should commence with the establishment of a transparent centralized research review and granting agency, akin to NIH or NSF in the United States[2]. The executive board in this agency ought to be headed by distinguished scientists, preferably those that have retired or are nearing retirement, thereby possessing no vested interests in forwarding their own research, and include a delegation representing the Minister of S&T of the central government. There have been recent reports in the Indian print media on the tabling of a similar proposal by some of India's leading scientists. However, nothing concrete has emerged from these talks. An application submission and review system, much like the one used by the NSF and NIH must be established and the agency must be provided with all the resources to efficiently, transparently and punctually review the grant applications. Given the futility of hypothesizing the greater importance of basic or applied research and the nebulousness of algorithms used to prioritize research, more debates are called for on this matter. However, given the sustained excellence of America's granting agencies, it is recommended that replicating several of their grant allocation policies enforced at a time when America faced similar national challenges is a desirable starting point[2].

Importantly, principal investigators applying for grants must be directed to mandatorily appoint post-doctoral researchers to assist with the proposed research despite investigator apprehensions of excessive staffing for seemingly simple research projects. Not only does appointing post-doctoral researchers serves as an effective means for training and recruiting new faculty, it creates a platform for employing many of India's 'unemployable' graduates by encouraging them to pursue higher degrees and thereby, adding to India's research workforce. Also, by being forced to support additional research personnel, principal investigators will be pushed into expanding the scope of their projects and 'creating' tasks for the seemingly superfluous staff. This, in the long term, should have a positive effect on the productivity of India's research programmes and favourably improve the cost–benefit ratio. The University Grants Commission (UGC) of India seems to have already caught onto this idea and in response, has recently launched several fellowship programmes, notably the D. S. Kothari Fellowship, to assist young investigators and encourage them to pursue bolder projects. This scheme must be expanded to develop a sizeable community of qualified university lecturers as well. The government should establish more international merit scholarships for post-doctoral researchers to conduct research at selected foreign universities, with the choice of destination governed by the MoUs signed by Indian universities with their foreign collaborators. MoUs between individual faculty members at Indian and foreign universities must also be remodelled to support training of Indian post-doctoral researchers in foreign laboratories. Importantly, a clause enforcing return and promising employment in the event of acceptable performance at the foreign university should be included in terms of these scholarships. This would ensure that the best Indian-educated post-graduates in the country are provided with the adequate means and enticement to conduct future research in India.

A parallel development to building research institutions in the country would be to reconsider some of the nation's intellectual property laws when it comes to university-generated innovation. University-based entrepreneurship is almost entirely dormant and several potentially useful technologies developed in the labs of India's universities have remained unutilized due to arcane intellectual property laws. Steps must also be taken to institute grants similar to the Small Business Innovation Research (SBIR) grants in the United States to stimulate establishment of high-tech ventures. The propensity of university-driven entrepreneurship to stimulate a nation's economy is aptly demonstrated by the case of Silicon Valley. Some of the programmes sponsored by the Department of Biotechnology and the Department of Science and Technology are a welcome change in this regard. Indeed, the New Millennium Indian Technological Leadership Initiative (NMITLI) under the aegis of CSIR has been an excellent concept where academia, government labs and industry are partnering on some very innovative ideas. Some of the NMITLI projects have yielded excellent results as was envisioned at the time of its inception[17,18]. These suggestions do not promise immediate results and it would be foolhardy to expect immediate change. What these suggestions do assure is a gradual swelling in the university-based research ranks of the nation and a gradual improvement in quality as the research becomes institutionalized. This process could take a decade or more but if successful, could unimaginably improve the quality of life in India.

Role of industry

India's industries too have a role to play in the reshaping of India. Despite industry-supported research being parochial in scope, industries represent a significant source of funds for research and should be adequately tapped. Without questioning the industries' motives for supporting research at universities, there is room to improve. The government should implement more favourable tax policies than those currently in place for industries that sponsor research at universities, and companies supporting research in domains beyond the realms of their market should be generously rewarded with sizeable tax reductions that are commensurate to the level of support to university research. Also, it must be seen to it that companies hiring university undergraduates as summer internships should also reap tax benefits. It is high time that co-op programmes with alternate trimesters in industry should be introduced in all engineering and technical institutes. The industry should be given generous tax breaks to support faculty positions, either through endowments or like regular employees. Private corporations could also be encouraged to mentor universities to expand their research repertoire to newer domains in order to foster knowledge creation without handing them any direct or indirect control of administration or recruitment. Additionally, industries should be invited to participate in university-led research consortiums such as the NMITLI with appropriately negotiated terms for intellectual property ownership and commercialization of technologies emerging from such partnerships. Such arrangements could synergize research competencies of corporations, provide universities with funds to operate strong graduate programmes, hedge risks associated with exploratory research as well as accelerate technology conception and commercialization. Attractive tax benefits for faculty endowments, library endowments, scholarships and financial assistance by way of interest-free loans are some other avenues by which industries could assist in reshaping India's destiny. Indian industry is more than capable of participating in this grand vision of education and must be rewarded suitably. Of course, this will call for more debates and discussions to build a robust policy.

Summary

Improving a nation's technical education system is directly correlated to its economic health and the social development of its population. One of the reasons for India's failings and America's dominance has been the outdated and ailing technical education system of the former and the excellence of the latter. It is believed that by selectively emulating the American model of higher education, notably technical education, India could usher in hitherto unimaginable waves of development that could vastly improve the standard of living of her citizens. Accordingly, steps have been suggested to achieve this difficult transition and chemical engineering education was used as a representative example for all branches of technical education. Several ways have been enumerated to modernize the curricula and teaching resources in place at India's universities and also build a strong research workforce to strengthen innovation. It is our firm belief that building a strong nationwide research competency will be of immense benefit to India.

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Conflict of interest

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