VIF TASK FORCE REPORT

TOWARDS MORE EFFECTIVE EDUCATION:

Emergence of STEM Education in India

Vivekananda
International Foundation

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Foreword

Science and innovation have been long-embedded in India's civilisation and culture. Today, they are playing an important role in shaping the country's future in an increasingly globalised world. The current pace of technological change across the world is unprecedented and is opening up new ways of manufacturing and creating knowledge and innovations. This creates huge opportunities for economic growth and social benefits for India's large population. However, to achieve these benefits, India needs to develop and grow human expertise in the inter-related fields of Science, Technology, Engineering, and Mathematics – STEM.

For the vast Indian population, which is at the cusp of rapid socio-economic transition, it is paramount to develop people's skills so that they can be meaningfully employed in specialised STEM sectors. STEM impacts on almost all employment types and careers and affects society at large. It is thus important that every individual in the society is able to develop the understanding of STEM and to fully engage with it. Apart from employment generation, the future advances in science and technology will also be essential to combating the greatest social and environmental challenges we face, and suitably qualified experts are required to tackle these.

In this context, the VIF had set-up a Task Force under the chairmanship of Prof. K.K. Aggarwal, Former Vice Chancellor, GGS Indraprastha University, New Delhi to examine the issues relating to STEM education in India. The report identifies the main issues involved in STEM education; provides guidance on how the industry can contribute to science education; and proposes a new framework for all types of science education from formal, to non-formal and informal approaches. It lays down the 21st-century vision on how best to equip Indian youth with the necessary skills through STEM education and foster the country's long-term economic growth and development.

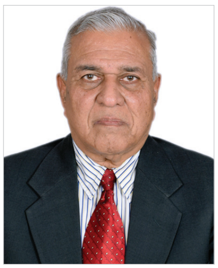
The experts offer several important recommendations and among other, the need to start the integrated B.Tech programmes which will align not only spur innovation and creativity in students but also serve requirement in India's growing small-scale industrial sector. The experts rightly identify the need to bring scientific temper to translate Indian society's strength of 'Jugad culture' into 'Culture of innovation'. For young people aspiring careers in STEM, the report identifies the need to bring emerging technologies and markets closer to the classroom, and also to fire the imagination of young children through innovative learning. This is mainly so keeping in mind the workforce requirements for future markets and innovative industries in India.

The VIF is pleased to publish the work of experts who have compiled this report and made a substantive contribution to the STEM education thinking within India.

New Delhi
25 March 2019

Dr Arvind Gupta
Director, VIF

Preface



By and large, India's present-day academic institutions are focusing on publications instead of products. This results in situations where national missions like 'Make in India' don't get due benefit of inherent Research and Development (R&D) potential of the country's scientists and academicians. This situation is thus not challenging the STEM higher education system to go in for drastic changes fast enough. Unless timely steps are taken, it may become too late to rectify the situation. The fast growth of India's service sector though very welcome, should not render us complacent in the manufacturing sector, nor prevent us from our fair share of creativity and innovation. India is a country full of talent which can rise to any occasion and our internal demand for good quality products can be very high. These factors should be enough to boost R&D in design as well as development of high quality, energy efficient, eco-friendly, cost-effective and sustainable products. It has not happened and we emphasise that we should not lose any more time.

Based on several rounds of deliberations, discussions with experts and perspective contributors, and some inputs from (VIF), the present report is organised in the form of seven chapters.

The first chapter discusses the status of development of higher education in general and the challenges it faces even today. It reflects on how India once had a very strong education system which has since been eroded and brings out the need for certain steps to be taken at an early date. It is pointed out that the entire system has been performing in *quality deficit paradigm* for quite some time and that an early reversal of this trend is absolutely necessary. Also discussed are global aspects and the challenges related to open education.

The second chapter specifically focuses on STEM education in India and its futuristic perspective. The reasons which have led to poor science education despite several interventions and initiatives are discussed in detail. The most imperative need is to develop a proper scientific temper, powers of observation, connection with nature and a need for pictorial thinking. The real strength of youth has to be strong scientific temper, intellectual content and imagination, rather than looking for quick-fix solutions to problems. Missions like 'Make in India' require educational institutions to focus on the training of graduates in the latest developments in science and technology to make them truly capable of penetrating the STEM workforce.

In chapter three, it is discussed in depth how creativity and innovative thinking are essential pre-requisites for meaningful STEM education. We do need creative scientists and engineers to solve the real problems facing society. The need to revisit United Nations Educational, Scientific and Cultural Organization (UNESCO) goals for meaningful impact creatively and constructively has also been brought out in this chapter. It is also emphasised that some STEM education will be required for enhancing creativity in all graduates, thus emphasising that creativity and STEM education form a mutually supportive chain and both have to coexist. Some implementable approaches to develop creativity amongst graduates at all levels are also discussed.

Chapter four discusses possible approaches for leveraging Information and Communication Technologies (ICT) for quantitative and qualitative growth of STEM education. As school education improves, higher education too will have to accommodate expansion. Taking a cue from the United Kingdom (UK) and Singapore, the need for developing computational thinking right from school onwards to university-level education has been brought out through a clear road map. Approaches for online education are discussed with concrete suggestions for increasing reach. The challenges in this journey are also mentioned to ensure we are careful in our course of action.

Chapter five brings out historical perspectives for the growth and development of STEM education in USA and China. In both countries, clear cut vision statements from the highest national platforms have been issued and adequate financial resources committed. More than a decade has passed since the USA defined milestones in STEM education in all its forms including medical and computer science. China has also introduced a new science and technology (S&T) policy, which lacked pace to begin with, but is now moving at an exponential rate. Some initiatives taken by China are described in this chapter, and India needs to adopt these at an early date.

It is to be appreciated that traditional manufacturing and service-oriented industries are being disrupted in a manner we have never seen before. The first Industrial Revolution was triggered by the invention of the steam engine which led to mechanical production. The second Industrial Revolution which was catalysed by electricity and the assembly line, made mass production feasible. The third Industrial Revolution from the 1960s onwards was driven by computers, digital technology and the Internet. The fourth Industrial Revolution is being driven today by a set of technologies that are transforming production. It is expected to lead to greater efficiencies and change traditional production relationships among suppliers, producers, and customers as well as between humans and machines. This fourth Industrial Revolution is set to make a very strong impact on new job opportunities and therefore changes in STEM education become even more imperative.

New job opportunities in STEM areas across the world are described in chapter six. It is discussed as to how certain areas of STEM education need to be focused on to ensure adequate quality manpower in rising technologies such as robotics, The Internet of Things (IoT), 3D (Three Dimensional) Printing, Artificial Intelligence (AI), Nanotechnology, Cloud Computing, etc. t is also brought out as to how comprehensive STEM education will be required for effective solutions to issues like climate change, inland water transport, infrastructure development, cyber security and use of block chain technology. Examples of new job areas anticipated are given with a clear focus on how levels of skill needed for any job will require a quantum jump and why we need to be ready for this straightaway.

Chapter seven discusses in detail the need for improving science and engineering education in the country, with a number of new models suggested. There has to be a clear shift towards integrating knowledge and skills in the right proportion for specific jobs in order to bring out the intrinsic capabilities of students. Keeping in view the diversity of our country, STEM education should also concentrate on resolving local and regional problems, We should also design courses for our small and medium-sized enterprises (SMEs) and small start-ups as it is the need of the hour. The need for developing STEM teachers and academic leaders in a meaningful way is also brought out. This chapter brings out many more concrete suggestions, which need to be attended to as soon as possible.

Finally, we give recommendations and an action plan in each case. Some of these could become 'game changers'.

In preparing this report, substantial information has been taken from newspaper articles, blogs and articles appearing on the Internet. At some places, references were available and have been mentioned. At several other places, primary/secondary/tertiary sources could not be easily identified. If some work is taken and not acknowledged, it is possible and regretted. An exercise of this kind has innumerable formal and informal sources which come into play. In any case this report is not a research publication and no originality is claimed except where specifically mentioned. It is indeed a status report with some suggestions for further discussions and deliberations.

As the subject of STEM education is very vast, it was not possible to cover all aspects. The focus was on higher education although some references to school education appear here and there. Engineering education reforms in the backdrop of STEM appear to be the top most priority in higher education.

It is hoped that the report will attract the attention of scientists and academicians and initiate implementable and scalable initiatives for the betterment of STEM education and higher education overall.

It may be appreciated that with so many eminent contributors minor overlaps between chapters could not be avoided completely. Readers may find some repetitions and overlaps. Another interesting observation is that several contributors have given their proposals, which really seem to be converging. This indicates that the 'time for critical changes has come'. It is for all of us to catch it and move ahead.

We are grateful to Dr. V.K. Saraswat, Professor R.K. Mittal, Dr. P.N. Pandit, Dr. H.S. Sharma, Dr. S.K. Chakravarty, Dr. R.K. Pandey and Dr. H.R. Mohan for their encouragement, valuable inputs and contributions. Dr. Arvind Gupta and Professor Brijmohan Suri were kind enough to read the entire report thoroughly and offer several useful comments and suggestions. Sincerest gratitude to Director, VIF, and his dedicated team for the publication of this report, which I certainly hope will germinate enough ideas to bring about change.

Professor K.K. Aggarwal
Chairman, STEM Task Force

Chapter 1: Higher Education in India – Developments, Status and Challenges

Higher education in India is passing through a phase of unprecedented expansion, marked by an explosion in the volume of students, a substantial expansion in the number of institutions and a quantum jump in the level of public funding. However, there is a dire need to emphasise quality, innovation, transparency and creativity, which somehow has been elusive in our higher education.

– 12th Five Year Plan Document

1. Introduction

The opening sentence of the 12th Five Year Plan Document reproduced above aptly describes the status of higher education in contemporary India. Much before Muslim and British rulers in India damaged our ancient scholarship and indigenous structure of education, universities and centres of higher learning such as *Takshashila*, *Nalanda*, *Valabhi*, *Kanchi* and *Vikramshila* were at their zenith. Nalanda University was an acknowledged centre of learning from 427 BCE to 1197 AD and reportedly had a student number varying between 3,000 and 10,000, and teachers between 1,510 and 2,000. It was run with the help of land grant revenues from about 200 villages. Before Nalanda University was demolished by white Hun and Turk invaders around 1197 AD, it was known across Asia and Europe as a glorious centre of learning for religion and philosophy. In fact, scholars from all parts of the then known world visited it in search of wisdom and new knowledge. Formally initiated as a centre of learning around 629 BCE, it was further strengthened in the sixth century BCE by Gautam Buddha and later by the Magadha, Shiskunaga, Nanda and Maurya dynasties (especially Chandragupta and Ashoka, the Great). King Ashoka's patronage helped in the growth of Nalanda as a fully residential university with about 10,000 students. Nalanda developed a well-organised elementary education system spread across monasteries and *gurukulas*, focusing on Buddhist and Vedic philosophy, grammar, logic, arts and political science (Kumar, 2015) [1]. Nalanda was established as a world-class university much before the first universities in Europe came up in Bologna (1088 AD) and the University of Oxford (1096 AD). When these great institutions went into oblivion, new universities of the same level of eminence could not be created due to a sharp decline in the quality of polity and governance in the country. However, the tradition of self-discipline and advanced learning continued due to the efforts of some wise men and women to keep us 'intellectually alive'.

British rule in India brought in English education, western sophistication, as also a discrimination and filtration policy. Thomas Babington Macaulay's plan was tailored to suit the requirement of the 'Raj' and led to the creation of clerks and bureaucrats to serve their masters. However, when we gained independence from the British in 1947, voices were raised and the dedicated efforts of the forefathers of the Republic to indigenise the system and serve changed realities succeeded to some extent, but much more remains to be done to take education to the last mile and to those isolated for centuries.

2. Expansion

When India became independent in 1947, the higher education system comprised of 20 universities and 591 affiliated colleges catering to 2,28,881students. These colleges were mainly managed by Christian missionaries. Higher education was small but elitist and catered to only the privileged few. However, fire is the test of gold and courage is the conviction of the brave. With faith in this dictum, the leadership of new born India began to raise a magnificent edifice for higher education as it was considered to be the most potent vehicle for socio-politico-economic development. Policies were formulated that emphasised that Indian education should cater to our genius, be rooted in the national ethos and stay coherent with cultural values. In fact, the system was expected to shun under performance and add value to the learning experience. In spite of a serious resource crunch, the system expanded @ 10 percent in the 1950s and 60s. However,

Table 1: Types and No. of Higher Education Institutions (2014-2018) [2]

Type	Sub-type	Number		
		2014	2016	2018
Universities	Central	42	43	43
	State public	310	316	329
	Deemed	127	122	122
	State private	143	181	197
	Central open	1	1	1
	State open	13	14	14
	Inst. of National Importance	68	75	75
	Inst. under State Act	5	5	5
	Others	3	3	13
	Total	**712**	**760**	**799**
Colleges	–	**36,671**	**38,498**	**39,071**
Stand-alone Institutions	Diploma (Technical)	3,541	3,845	3,867
	PG Dip. Management	392	431	435
	Diploma (Nursing)	2,674	3,114	3,060
	Diploma (Teacher Trg.)	4,706	4,730	4,403
	Inst. under Ministries	132	156	158
	Total	**11,445**	**12,276**	**11,923**

Source: aishe.gov.in Ministry of Human Resource Development, MHRD, 2014; 2018 more institutions of similar type were cloned, leading to the creation of a vast higher education system. For the period 2014-2018, the growth is shown in Table 1. As of 2018, we had 799 universities, 39,071 colleges and 11,923 stand-alone institutions. It is pertinent to mention here that the system witnessed an increase of 87 universities, 2,400 colleges, and 478 stand-alone institutions during the period under reference.

The availability of higher education has increased significantly. In absolute terms, the expansion of the higher education system in India has been phenomenal. There has been a considerable increase in student enrolment over the past five years (Table 2) [2]

Table 2: Enrolment 2013-14 to 2016-17

	2013-14	2016-17
Enrolment	30.1 million	35.7 million
Degree-wise		
Graduate	86%	79.28%
Postgraduate	12%	11.33%
Dip./Cert.	1%	8.47%
Research	1%	About 1%
Area-wise		
Arts	37%	40%
SC	18%	17.48%
Commerce, Mgmt.	17%	16.32%
Eng. & Tech.	16%	9.64%
Education	3.6%	5.39%
Medicine	3.5%	5.07%
Law	2%	1.16%
Agriculture	0.5%	0.48%
Vet. Sc.	0.14%	0.08%
Others	1%	1%

Source: UGC 2013; MHRD 2016; UGC 2017

The Gross Enrolment Ratio (GER) in the period under reference changed from 19.4 percent to 25.2 percent and it is projected to increase to 30 percent in 2020-21 (MHRD, 2018) [2]. Similarly, the Gender Parity Index (GPI) improved from 0.86 to 0.94. This became possible through positive discrimination policies of the Government of India (GoI) with particular emphasis on increasing female enrolment in the Indian Institutes of Technology (IITs) (to the tune of 14 percent) as well as the Indian Institutes of Management (IIMs). The National Sample Survey Office (NSSO) had also recorded a tangible shift in GER in terms of inclusiveness for socially backward groups between 2007 and 2014 – STs (7.22 percent to 17.19 percent), SCs (11.35 percent to 22.31 percent), OBCs (14.57 percent to 29.36 percent), others (26.22 percent to 41.65 percent) [Sabharwal and Malish, 2016; Chaudhary et al, 2016]. This is a clear indication that higher education in India is moving towards the greater inclusion of the marginalised, isolated and excluded.

While releasing the 8th All India Survey of Higher Education (AISHE) 2016-17 in January 2018, Union HRD Minister Prakash Javadekar highlighted the government's major priorities, including emphasis on quality, autonomy, research and innovation. This was reiterated in his message on 30 October 2018 at the FICCI conference on Universities of Future held in New Delhi. But as we know, global surveys show that there is no world class Indian Higher Education Institution (HEI) which ranks in the top 100 institutions. Even at the regional level we have very few high quality institutions. Moreover, even the numbers of citations of research paper published by Indian researchers has been decreasing steadily and it is worrying to learn that employability of graduates is rather low.

3. Challenges

A quick perusal of growth in the higher education system shows that all has not gone as per plan. In fact, prior to the 11th FYP, no plan document of the State or Centre ever contemplated the number of universities or colleges to be established or the enrolment ratio to be achieved within a Plan Period. Consequently, in spite of a quantum jump in the level of funding in the 11th Five Year Plan (2007-12), higher education in India continues to face several challenges and limitations. Some of them are as follows:

1. Satisfactory 'under-performance' syndrome, which has affected the quality of education, crippled the creativity of both students and teachers, leaving them demotivated. The mobility of talent across universities has almost completely vanished. Moreover, every care is taken to 'maintain seniority' rather than reward merit. This warrants mid-entry of talent in the education sector similar to the government move to recruit technocrats and professionals from the corporate sector at the joint secretary level with the objective of introducing applied domain knowledge to enrich the quality and relevance of curriculum.
2. The system has to deal with politico-bureaucratic culture and due attention is not accorded to true scholarship, merit, transparency and excellence in academic, administrative and financial management.
3. The professoriate has failed to resist the temptation to be close to the seats of power and assert for the right cause.
4. Wisdom and knowledge are not in equilibrium due to lack of emphasis on the value of teaching-learning institutions. Moreover, politicisation at all levels: students, teachers, and non-teaching staff, is doing serious harm to the system.
5. The system is inflexible, and not so relevant to the needs of a knowledge society from the 21st century and unequal to the task of meeting the requirements of higher education for all due to limited capacity. Moreover, the system has been performing in quality deficit paradigm, particularly in serving the 'social cause' (Prasad, 2015; 2018) [3]. According to the National Knowledge Commission (2006, 2009), there is a 'quiet crisis in higher education that runs deep... the general impression is one of mediocrity' and a few islands of excellence (in a sea of mediocrity) that do exist today do not do justice to our collective genius. We have to reorient it towards quality and excellence which are defining elements of the knowledgeable era.
6. The system has low productivity due to the lack of seriousness in research, accountability of action and transparency in administration and governance.
7. Due to political expediency our higher education system has followed a piecemeal approach. The system produces unemployable graduates who do not possess skills needed to compete in a knowledge society.

8. The higher education system is highly fragmented and multi-layered, and has a wide spectrum of institutions, from a national university in a cosmopolitan city to a college in a remote village with vast differentials in facilities.

9. The growth of higher education in the past two decades has been driven by private providers who are guided more by 'for-profit' (though veiled) rather than humanitarian considerations, and there is a lurking fear of cross-commercialisation of higher education. The system continues to deny benefits of education to the latent pool of talent among the poor, isolated and the marginalised.

10. Most Indian universities are of the teaching-cum-affiliating type and several of them affiliate 800 or more colleges (Tyagrajan, 2015) [4]. Moreover, the transaction of knowledge in the majority of institutions continues to be based on 'chalk and talk' method, which neither encourages innovation nor incubates creativity.

11. Higher education has been starved for funds and infrastructure – library resources, laboratories, equipment, ICT – as well as human capital. We do not have even a critical mass *of dedicated educators and researchers*. In fact, now we have fewer researchers – 4 in 10,000 – among working professionals, lower than even Kenya and Chile. We spend only about 0.02 per cent of GDP on research.

12. The system has been overregulated by a multiple of bodies which sometimes work at cross-purposes to keep their respective spheres of influence intact.

13. The system has failed to be competitive and entrepreneurial. Intellectuals prefer to work abroad; even world class universities are hesitant to open their campus branches in India.

To sum up, major challenges that the government has to necessarily address include: i) access and inclusive education; ii) skilling and employability; iii) quality of teaching-learning including technology-enabled education; iv) quality of teachers/ educators and their continuing professional development; v) scale and quality of research (and development) including socio-economic relevance, global competition and citations, and global standards; and vi) funding and financing for education and training.

4. Budget and Resources

Financing higher education has been one of the key issues in all debates on higher education. With the landscape of higher education changing continuously and rapidly, it is logical that a funding pattern suitable to new realties will evolve. The core principles of financing education in India since independence have been of 'socialistic concept of welfare state' and for 'social good'. However, the beginning of the liberalisation era in the 1990s marked a definite transition. Central and state governments continued to be major sources of funding at all levels between 1950-51 and 1990-91. The share of central and state governments increased from 57.06 percent to 87.87 percent, while there has been a drastic fall in the share of student fees (20.39 percent to 3.54 percent), endowments (11.62 percent to 2.37 percent) and local governments (10.93 percent to 6.22 percent) (Azad, 2008) [5]. To compensate for reduction in the contribution of student fees, student loans have emerged as one of the major sources of funding educational expenses. In the case of higher education, while only Rs. 171.5 million was spent with 843 HEIs in 1950-51, the amount increased to Rs. 10,532 million in 1980-81 with an annual growth rate of 14 percent, though the recurring expenditure per unit declined by 10.5 percent (Tilak and Varghese, 1991) [6].

Central universities are funded by the University Grants Commission (UGC), a few others also get central assistance from the UGC but a majority depends either on state funding or self-financing. In 2017, the UGC funded 208 out of 360 state public universities, three out of 262 state private universities, nine out of 123 deemed universities, and 8,993 out of 42,338 colleges (UGC, 2017) [7]. Today only about one percent of GDP is spent on higher education while the target is to reach 1.5 percent. The drop in government funding support has been complimented by increase in privatisation/self-financing colleges and universities, particularly for professional education. Though it is an accepted norm in educationally advanced countries, in India, private providers (with the exception of a few) have been more for profit and low on humanitarian and philanthropic considerations.

As the financial resources required for education in general and higher education in particular did not prove adequate, the government enhanced education and health cess in 2018 from 1% to 4% (including 1% for secondary and higher education). Further, as part of revamping the regulation and governance of higher education, the government has created a Higher Education Financing Agency (HEFA) to take care of the requirement of Revitalising Infrastructure and Systems in Education (RISE) with an estimated investment of Rs. 1 lakh crore through loans (not grants), and to meet the new infrastructure requirements of centrally-funded institutions (who, henceforth, will not directly receive any such grants). The new initiative also includes a Rs. 3,073 crore grant for developing a few Institutions of Eminence. (Under this initiative, six existing institutions have been identified and announced. A few more are under active consideration.

5. Public Good versus Trade

With the introduction of WTO-GATS in 1995, the initiation of economic liberalisation in 1990s and further liberalisation by the government of the day to be internationally competitive in exports and skill development, it is being argued that if education can be considered public good – something which each citizen can benefit from without paying too high a price – i.e., non-rivalry (available to any additional individual or group), non-excludability (benefit to and cost to each one through measures such as education and health cess) and externalities (not influenced by market forces) (Tierney and Sabharwal, 2016) [8]. While it is true that a student pays much less than what one gains or what the government spends per unit, there is much debate about private universities/private higher education. In the US, the distinction between for profit and not-for-profit private universities is very clear – in the former, there is generation of revenue and profit by any means, including public trading of the institution, while in the latter, there is no provision to generate revenue for staff and board members and also external revenue. In comparison, in India where for-profit colleges and universities are not allowed (under pseudo-private initiative in education), what operates on ground (with the exception of a very small percentage) are profit-making and commercially-oriented professional colleges and universities. In fact, India has a very unprofessional notion of private initiative/ privatisation (barring the traditional few philanthropic establishments like Dayanand Anglo-Vedic), culminating in consideration of surplus/profit-making, rather than R&D and national development.

There is considerable cost variance, so also quality, across institutional types. It is not justifiable as to why such a huge gap in unit cost should be allowed. For instance, while the cost of a four-year UG degree in USA costs USD 282,400 (Stanford), and USD 242,400 in a public research university (San Diego), in India in a private university it is USD 40,000 (Ashoka), public residential USD 10,000 (IITs), and public non-residential USD 60 (Presidency College) (Kumar, 2015) [1]. Yet several thousand students go to USA for higher education largely because of quality of education.

Table 3 shows the decline in public expenditure on higher education per student (percentage of Gross Domestic Product per capita). As may be noted, the percentage of GDP per capita in India is much higher than in

Table 3: Public expenditure on higher education per student (% of GDP per capita)

Country	1990-91	2006	Change
UK	40.9	27.6	– 13.3
Australia	50.7	22.5a	– 28.2
New Zealand	67.8	25.2	– 42.6
Chile	27.1	11.6	– 15.5
Czech	45.9	30.4	– 15.5
Nepal	90.8	71.1a	– 19.7
Malaysia	116.6	71.0	– 45.6
India	**92.0**	**61.0**	**– 31.0**
Estonia	55.9	18.2	– 37.7
South Africa	90.9	50.1	– 40.8
Hungary	81.3	24.3	– 57.0
Jamaica	132.3	40.7a	– 91.6
Regions			
High income countries	47.1	29.0	– 18.1
South Asia	90.8	68.6a	– 22.0
Upper middle income countries	61.8	23.3	– 38.5

Source: Tilak, 2008 [9], a refers to 2005 many other countries. The government holds the key to education as public good through provision, regulation and funding. All three at present, seem to be slipping away and are skewed toward private players/privatisation. Universities no more remain as public good in the strict sense of the term (as in the case of Mexico and Saudi Arabia, where it is fully funded by the government); it may now be 'impure public good' (in contrast to pure public good) (Tierney and Sabharwal, 2016) [8]. In India, this is called 'private initiatives in education' which control about 80% professional and 60% general education (Prasad 2018) but always argues against strict government regulation. On the other hand, one can easily evaluate if such private colleges and universities have contributed to national Intellectual Property Rights and the patenting basket, and to the world ranking of universities. Two instances may be brought in to examine the nature of higher education as public good – enrolment of SC/ST students and the student fee structure (Tierney and Sabharwal, 2016) [8].

Tables 4 and 5 clearly indicate that while private institutions (aided and unaided) charge much higher fees from students than the public HEIs, they are far behind in enrolling SC and ST students in comparison.

6. Internationalisation

At the instance of promulgation of WTO-GATS in 1995 (to which India is a signatory), education was treated as a service and a marketable commodity. Within the framework of free international trade, four modes of delivery were visualised for education –

Table 4: Student enrolment in HEIs (%) (2014)

Type	STs	SCs	OBCs	Others	Total
Government	58.80	48.56	37.35	38.83	41.42
Private Aided	21.96	22.32	25.00	26.15	25.34
Private Un-Aided	19.06	28.66	37.07	34.43	32.69

Table 5: Student fee structure – annual (Rupees) (2016)

HEI	Undergraduate	Post-graduate
Central University (JNU)	370 (BA)	370 (MA)
State University (Lucknow)	4,719 (BA)	3,377 (MA)
Government College (Zakir Hussain, DU)	7,810 (BA)	9,544 (MA)
Private University (Shiv Nadar)	264,500 (BA)	–
Private University (O.P. Jindal)	349,500 (B.Tech) 765,000 (BA)	466,000 (MSc) 465,000 (MA)
Private Aided (Jai Hindi, MH)	3,742 (BA)	10,792 (MA)
Private Unaided (KITM, Kurukshetra U.)	76,200 (B.Tech)	76,200 (M.Tech)

cross-border delivery, consumption abroad, commercial presence and service abroad. The major contention was export of higher education abroad and import of more overseas students. Table 6 shows the flow of overseas students from different continents to India, which is not very encouraging to say the least.

The status of foreign students studying in India is shown in Table 7 (Ministry of Human Resource Development, 2018) [2]. As may be noted, the data for 2017 shows an improvement over previous years. The government has been making attempts to showcase India's great culture abroad to attract more students to come to study in India.

As may be seen from Table 8, about six million students study overseas, though the largest contributor is China. About three lakh Indian students go abroad for higher education, especially to the United States. After Brexit (The United Kingdom's decision to leave the European Union), and especially due to problems associated with recognition of one-year degrees of Commonwealth countries including the United Kingdom, the number of Indian students in British universities has been declining (and the government, in spite of best efforts, has not been able to solve this problem of equivalence). The government has not yet succeeded in inviting foreign providers to establish direct campuses on Indian soil, though they are offering programmes through twinning arrangements.

Table 6: Overseas students in Indian universities (1995-2013)

Years	Africa	Americas	Asia	Europe	Oceania	Others	Total
1995	4081	309	4831	127	40	699	10087
1996	2680	163	2735	91	28	144	5841
1997	2536	140	3605	151	35	234	6701
1998	2085	124	2733	111	32	238	5323
1999	2558	275	3492	120	31	512	6988
2000	2969	327	3866	180	44	405	7791
2001	2369	432	4312	253	45	732	8413
2002	1904	353	4452	145	40	862	7756
2003	1755	475	4809	128	42	544	7753
2004	2005	593	9849	178	55	587	13267
2005	2403	654	10493	206	71	629	14456
2006	3316	776	13400	238	69	592	18391
2007	3796	626	15437	309	81	957	21206
2008	4193	614	16004	304	66	597	21778
2012							
2013	5799	686	23350	293	124	864	31126

Source: P. Panda (2017) [10].

Table 7: International students in India (2013-2017)

Year	Male	Female	Total
2013	21,582	12,933	34,774
2014	25,565	13,953	39,517
2017	31,779	15,796	47,575

Source: MHRD, 2018 [2].

Table 8: Indian students going abroad vis-à-vis status of international students globally (2000-2014)

2000		1,54,000	22,000	1,20,000	67,000
2006	30,00,000	2,42,000	27,000	1,25,000	1,58,000
2007	na	2,62,000	24,000	1,22,000	1,61,000
2008	na	2,60,000	22,000	1,74,000	2,18,000
2009	37,00,000	2,71,000	23,000	2,27,000	2,27,000
2010	na	2,73,000	23,000	na	2,54,000
2011	41,00,000			3,39,000	na
2012	45,00,000	2,74,000	28,000	3,37,000	2,22,000
2013	47,00,000	3,04,000	na	4,15,000	2,00,000
2014	50,00,000	Na	Na	4,59,000	na

Source: P. Panda (2017) [10]. na= not available

7. Teaching-Learning and Technology

In higher education, teaching has been one of the weakest areas, though attempts have continuously been made by academic administrators and planners to improve its quality. However, progressive institutions such as IITs and IIMs have kept pace with international developments in research for teaching-learning. But by and large, conventional higher education systems have continued to resist change and refrained from using technology in curricular transactions. Either due to their ignorance or otherwise about the capabilities of and value addition by media and technology, conventional teachers have viewed it as an agent that would impede their skills, marginalise their roles and adversely affect their importance. However, such impressions are misplaced as in reality technology enhances the reach of the word of mouth as also the effectiveness of a teacher in spatial and temporal dimensions. In fact, the growth of education has a direct correlation with technological developments despite the fact that no media or technology can replace, simulate or even imitate 'the teacher' in the classroom truly and completely. But the vast majority is following the age-old lecture method with note taking, without practicing what is learnt and without engaging real-time students with application in the field and in the community.

Insofar as availability of technology for education is concerned, India has kept pace with the developments and applications of ICTs for education and training. Starting from the SITE experiment of 1975, through developments in radio and television, teleconferencing, interactive multimedia, to online resource repository and online learning platform of SWAYAM, there have been significant developments in the country (Panda and Garg, 2018) [11]. But the major problem has been that all these ICTs and related pedagogies/andragogies of teaching-learning are at the periphery, sporadically used as supplementaries and operate in a context where there is a lack of holistic and innovative use for teaching-learning and research.

In an excellent recent anthology with reference to faculty, Kumar (2015) [1] has quoted the president of Thapar University noting the typical: 'the faculty quality lacking in India in four significant ways: 1) faculty members did not care if the students learned, 2) they also did not provide context on why students must learn concepts and theory in that class, 3) they taught from decades-old notes and slides, and 4) there was no application to real-world problems'.

To improve the situation, the government has undertaken many initiatives, including the *Global Initiative of Academic Networks* (GIAN) to bring in expert overseas faculty to Indian universities to teach for at least a semester. Besides the traditional NAAC assessment, the *National Institutional Ranking Framework* (NIRF) has also put pressure on HEIs to improve evidence-based teaching and engagement in student learning. A recent government press release underlined that 'Global academic rankings of the World Universities are carried out by multiple agencies. In one of such kinds of ranking exercises, the Times Higher Education World University Rankings 2016-17 has listed 31 Indian universities among the world's best universities, even though none of these figured among top 200'. (GoI, 2017b) [12a].

In recent years, the government initiated some reformative schemes, including: *Choice-Based Credit System (CBCS), Universities with Potential for Excellence (UPE), Centres With Potential of Excellence in a Discipline Area, Special Assistance Programme (SAP), Basic Science Research (BSR), Community Colleges (CCs), B. Voc degrees, Deen Dayal Upadhyay Kaushal Kendras, Scholarship Scheme for Northeast (Ishan Uday),* PM research scheme for meritorious students, new NAAC methodology, UGC Regulation 2016 for research degrees, and UGC Regulation 2016 for SWAYAM in which up to 20 percent of credit hours in an academic programme can be earned by a student through online learning at the national platform of SWAYAM. It is another matter that the quality of videos, the pace of progress by various national coordinators and the integration of SWAYAM to larger teaching-learning community, are still wanting to a large extent.

Another dimension that has emerged in higher education in recent years is *Knowledge Management* (KM). We know that knowledge is contribution of scholarly pursuits and management – capturing, storing and communication – of what is available in public domain, benefitting newer groups through the provisions of more effective environments. KM also seeks to transform our intellectual assets into enduring value. Technological tools and digital media can be used to create open resources, portals and e-repositories of the best materials, practices and techniques developed by the best minds. Such knowledge pools can also be used to preserve our cultural heritage, which has sustained us since ancient times.

8. Research and Development

Research is one of the finest outcomes of human intellect and is fundamental to the intellectual morale of every society. But *research develops discipline of dissent*. While engaged in creative and intellectual work, a researcher addresses questions that actively and continually challenge the discipline's frontiers. Moreover, research supports rational debate, unbiased examination of facts and ability to question existing practices and theories in the light of new evidences. And what is more important is the fact that research is intrinsically coupled with and teaches us the practice of values such as honesty, integrity, rationality, creativity, innovation, objectivity, truthfulness, foresight, openness to self-correction, dynamism, non-adherence to dogma, unflinching dedication and inclusivity. These, as we know, are basic values for a healthy social system. For the same reason, the practice of plagiarism in research must be discouraged in every way possible. The UGC has recently circulated regulations relating to strict punishment for plagiarism in research theses and teachers' publications. The outcome of research satiates human curiosity to explore newer horizons and go beyond the known. This aspect has led to a continuous pooling of knowledge ever since inhabitants of an African cave provided the earliest evidence of fire control by our ancestors some million years ago.

Quality research requires monetary investment and a very deep rooted culture of advance learning. Moreover, teachers, who are the cornerstone of the sense of learning within the system, ought to be dedicated researchers. Only then, can we satisfactorily address the root cause of our backwardness in research in comparison to the global standards (number and quality of publications). Now that the MHRD is engaged in formulating a new education policy, it is important to involve 'unconventional thinkers', in addition to 'established experts'. India's research output used to be comparable to the best in the world. However, this is not so today. The reasons are many – poor quality of Ph.D. work, lack of rigorous research training, disrespect to research as a career, poor quality of research skills by faculty, reduced research funding, disconnect between social, industrial and lifestyle requirements and individual research interests, among others. The introduction of quantified Academic Performance Indicators (API) by the University Grants Commission without any respect for quality has led to a mushrooming of low quality, but indexing services-compliant research publications in journals, especially initiated by commercial-minded private universities and publishers. Lack of professionalism in research and development, as well as decision-making by concerned regulators/policymakers is a major concern. Kapur and Mehta (2017) [13] have reported the following status of publications and citations which may not have changed much in recent times (Table 9).

Table 9: Publications and citations globally (1990-2011)

Year	USA		China		India	
	No. of Pub.	No. of Citations	No. of Pub.	No. of Citations	No. of Pub.	No. of Citations
1990	130,559	–	6,104	–	12,346	–
2001	150,817	2,894	25,730	174	15,522	103
2011	184,253	3,137	122,672	980	36,456	191

In the 1990s, India was far ahead of China. This got reversed in the 2000s and now India is no match in terms of comparison to the latter. In 2014, India was spending only about 0.85 percent of GDP on research, which was 4.29 percent for South Korea, 3.58 percent for Japan, 2.84 percent for Germany, 2.74 percent for USA, and 2.10 percent for China. This is very disheartening. However, to augment research, the government has launched two schemes recently – *Impacting Research Innovation and Technology* (IMPRINT) and *Uchhatar Aviskar Yojana* (UAY) (GoI, 2017a) [12b] – the former relates to research in HEIs with an allocation of Rs. 487 crores for the next three years and the latter with Rs. 475 crores of allocation is meant for industry-sponsored outcome-oriented research. The recently launched Prime Minister's Research Fellowship Scheme should competitively facilitate about 1,000 BTech graduates to pursue PhD in the best of IITs and IISc; and this is aimed at enhancing the quality and impact of research in science and technology.

9. Distance Education and Online Learning

Distance education (hereafter referred to as DE) in its earlier incarnation as correspondence education was initiated in the University of Delhi for UG Arts courses in 1962 with 1,111 students. While inaugurating the course, then Union Education Minister Dr. Shrimali outlined three objectives of correspondence education:

1. An efficient and less expensive method of educational instruction at the higher level in the context of national development.
2. Facilities to pursue higher education to all qualified and willing persons who had failed to join regular university courses due to personal and economic reasons or because of their inability to get admission to a regular college.
3. Opportunities of academic pursuit to educated citizens to improve their standards of knowledge and learning through correspondence instruction without disturbing their present employment (Ahmed & Garg, 2015, p. 179) [14 p.179].

Since then, the system has expanded rapidly, with the promise of wider access, inclusiveness, innovation, and employability – and anytime, anywhere education. The functional status of distance education/ open education in the country has been appropriately remarked by Ahmed and Garg (2015, p. 182) [14 p.182] as follows (Table 10):

Table 10: Functional status of distance and open education

Year	Open University (Number)	Correspondence Course/Distance Education Institutes (Number)	Remarks on status
1962-81	–	33	Correspondence era
1982-85	2	05	Transition to open era
1986-00	7	32	Consolidation of open era.
2001-06	5	34	Expansion of ODL and march to online education
2007-10	1	82	Era of misplaced priorities
2011-14	–	44	Indiscriminate growth
Total	15	230	Identity crisis

In parallel, there have also been developments in technologies and networks which eventually supported distance and online learning (COL, 2015) [15]. Some of these are as follows:

1. INFLIBNET (Information and Library Network Centre) was established in 1996 to provide network of all libraries in higher education and provision of Internet connectivity (UGC-Infonet connectivity).
2. *National Knowledge Network* established in 2005 for providing high-speed broadband connectivity to all education and training institutions free of cost.
3. Initiatives in establishment of community-based multipurpose tele-learning centres (Panda & Chaudhary, 2001) [16].
4. *National Mission on Education through ICT* (NMEICT) by Government of India since 2009, and offer of interactive free curriculum-based digital content through open source portal *Sakshat* for both student learning and teacher empowerment; and the initiation of NPTEL by Indian Institutes of Technology (under NMEICT) for creation and offer through Sakshat portal digital video content on engineering and technology free of cost.
5. *E-Gyankosh* (national electronic knowledge repository) of Indira Gandhi National Open University (IGNOU).National E-Library for providing free quality digital content from premier higher education institutions democratically accessible to students, working professionals and researchers.
6. *E-Pathsala* (electronic class) programme of UGC to fund institutions of higher learning to develop digital e-content (i.e., combination of print, powerpoint, video) based on college and university syllabus and make available as OER.

7. '*Digital India*' initiative of the present National Democratic Alliance (NDA) government to make the entire country digitally literate and empowered. The latest government online MOOC (Massive Open Online Course)-based portal for free credit-based content delivery, i.e., *Study Webs of Active-Learning for Young Aspiring Minds* (SWAYAM). The platform provides for self-eligibility checking through course preview, and interaction with online course coordinators/tutors towards credit-based course completion and credit accumulation towards a final diploma or degree.

These technological developments have been largely led, as also utilised, by the DE system in general. However, as a matter of policy, it needs serious consideration for the future in so far as funding of higher education and distance education/online learning is concerned. According to Kulandai Swamy (2002) [17]:

> *Either at the time of establishing the IGNOU or later, the Government of India has not articulated a unique funding policy for the open-university as such, distinct from the policy followed in funding of conventional universities. Generally, the analysis of costs and benefits of university education has not been attempted ….. It is only recent years that economics of higher education has come to be discussed and the universities are asked to generate funds' (p. 64).*

As per Government of India (GoI) Gazette notification 44 of 1 March 1995, the Distance Education Council (DEC) started giving programme recognition for DE programmes offered by public universities (though online programmes were not conceived within this framework of regulation). Guidelines were developed for the establishment and functioning of DE institutions and offer of academic programmes. Unfortunately, unlike other regulators of higher education [like Medical Council of India (MCI), All India Council for Technical Education (AICTE), National Council for Teacher Education (NCTE), etc.], the DEC was not created by an Act of Parliament. It therefore did not have a full-fledged legally-tenable regulation, norms and standards for various programmes. Therefore, it began by providing only guidelines as advisory. It started programme evaluation for programme recognition in 2003 and after five years it started offering provisional institutional recognition, a provision which was reportedly exploited and led to malpractices.

Pending the approval of the DECI Bill by the Parliament, the UGC has put in place regulations separately for distance education as also for online learning. It is presumed that most universities will initiate programmes through online learning within and outside the country and that DE will be closely scrutinised, hopefully by DE experts.

10. Professional Development of Teachers

In ancient times, teaching was well-defined and included the *guru-shishya paramparaa* (teacher-student tradition) organised in the *gurukul* (teacher's cottage). Teaching was considered *dharma* (way of life), so also learning. The teachers were well acquainted with the individualised pathways of students to facilitate individualised progression, as also a cross-understanding of individual pathways at least through the mechanism of *dharma* – community ways of living. Those who received higher learning/wisdom paid back to society by either becoming a teacher (guru) or as royals who would learn the art of governing and pay back to society. This arrangement though was limited to a select few. Subsequent developments brought in issues of access and equity to focus and during colonial rule got more formalised in forms of entry qualifications (including teacher training), recruitment policies, length of service, code of professional ethics, salary structure and retirement benefits.

Professional development of teachers in higher education was started in the 1960s with the UGC's 'summer institutes', followed by training in methods of teaching of fresh and junior teachers by a few universities in the 1970s, also one-year Masters by Calicut and Annamalai, Diploma by Bombay and Madras, a certificate by Madurai, and continuing professional orientation of in-service teachers by M.S. University, Baroda. The Mehrotra Committee report on Revision of Pay Scales of 1987 led to initiation of a PGDHE (Post Graduate Diploma in Higher Education) by IGNOU, and establishment of 44 Academic Staff Colleges for orientation programmes and refresher courses in 1987 with funding by UGC and professional coordination by NIEPA (National Institute of Educational Planning and Administration). In the absence of such nation-wide continuing professional development programmes earlier, the Academic Staff Colleges (ASCs) did a reasonable job in both pedagogy of teaching-learning and discipline refresher, notwithstanding suspicion of the dubious quality prevalent in many ASCs. The quantitative achievement can be seen in Table 11.

Based on 2015-16 data for 22 ASCs for the financial year, the total number could be 330 Orientation Programmes (Ops) with about 10,000 participants and 660 Refresher Courses (RCs) with about 30,000 participants. As a rough estimate, about 168,000 teachers would have attended OPs and 336,000 teachers would have attended RCs. Therefore, out of 1.42 million teachers about 1.25 million higher education teachers are yet to be oriented or trained. The AICTE (The All India Council for Technical Education) has its own teacher development programmes and since the introduction of the blended learning model

Table 11: Number of teachers trained in ASCs (1988-2016)

Year	Orientation		Refresher		Total	
	Progs.	Participants	Progs.	Participants	Progs.	Participants
1987-88	158	4,946	26	649	184	5,595
1990-91	630	18,583	650	17,808	1,280	36,391
1993-94	1,015	28,665	1,567	41,790	2,582	70,455
2015-16*	71	2,946	127	4,823	198	7,796

* Data for 22 universities available and reported.

Source: Sharma (1995) [18], Chaurasia (2017) [19], Panda (2018) [20] in 2013, it supports innovative professional development programmes through its Career Development Bureau (CDB) and funds Quality Improvement Programmes of the IITs and programmes of the Indian Society for Technical Education, among others.

The NAAC (The National Assessment and Accreditation Council) (2012) [21] rated 53 out of 66 ASCs as either under-performers or non-performers. Therefore, not surprisingly, the ASCs have, since 2015, been converted into human resource development centres under the Pandit Madan Mohan Malavia National Mission on Teachers and Teaching (GoI, 2015) [12c]. Under this mission, schemes for enhancing teaching-learning higher education through 30 Schools of Education in universities are being established. So far, about 12 have been established by the NCTE and the UGC between the years 2015 and 2017. Fifty Centres of Excellence for Curriculum and Pedagogy, five Centres of Excellence in Science and Mathematics Education, 25 Teaching-Learning Centres, 20 Faculty Development Centres, four Inter-University Centres for Teachers Education (about three are operational by NCTE and UGC), Innovation Centres, Subject Networks, one Higher Education Academy, five Institutes of Academic Leadership and Education Management are also being established. The AICTE has also initiated the process of establishing a compulsory pre-service teacher education programme and the UGC has been talking about the need for having a compulsory pre-service certification for higher education teachers.

Subsequently, the UGC suggested that Academic Performance Indicators (APIs) be formulated and used for promotion. The 2018 Regulation of the UGC has significantly done away with the old API system; though scoring has been retained with changes in the indicator system. While research publications and citations are considered important, what has come to the forefront is engagement in development of and teaching through MOOCs and OERs (Open Educational Resources), and other innovations in teaching-learning. Arguably, this Regulation 2018 has not been able to address the widely-held criticism that any individual and/or institutional assessment has not been able to comprehensively address the issue of '**the process of teaching-learning, including student assessment**'. This is the most important concern in Indian higher education as has been elsewhere in the globe and this needs to be urgently addressed. It is presumed that the recent policy initiation by the government towards revamping the UGC into an assessment and quality assurance agency might address the above concerns.

Given the entire spectrum of higher education and its quality enhancement, the continuing professional development of teachers, including pre-service and in-service, is one area (besides the effective deployment and use of ICT/educational technology teaching-learning) which is the most neglected and needs to be seriously addressed if quality higher education is to be enhanced and respect of the teacher in society is to be restored.

11. Governance

The governance of any institution of higher education in India is influenced by government policy/higher education regulators, the Acts and Statutes on the university (affiliating university for colleges) and the management body of the institution. The governance/ decision making is influenced by the state, the market and society. Government control that was prevalent since independence got reduced in the 1980s due to a fiscal crisis and that space was taken over by private entities (Varghese, 2015) [23]. State control took the shape of state supervision through various regulators and assessment agencies, including the NAAC and The National Board of Accreditation (NBA). The national control-based policy and decision-making moved toward more market friendly provisions of efficiency, performance enhancement and performance-based funding. At the state level, based on UGC 1988 guidelines, state governments established State Higher Education Councils (SHECs) to plan and coordinate, promote academic excellence, and advice on funding and research. One SHEC was established in Andhra Pradesh the same year, followed by many states (eight SHECs by 2014). This is part of the process of according more autonomy to states as recommended by the UGC Committee on Governance in 1968, the Gnanam Committee of the UGC, and the CABE Committee on University Autonomy 2005 (MHRD, 2005) [2d].

The MHRD of late has proposed autonomy to IITs and IIMs though fixation of student fees remains a contentious issues, for which the PMO has desired non-interference by MHRD and to leave it to students and institutions to decide (Vishnoi, 20-18) [24], besides establishing 20 world-class universities, the government also called for institutional concurrence for obtaining autonomy in all matters with a view to enhancing institutional excellence and quality of higher education. The central government has set aside Rs. 3,073 crores for supporting Institutes of Eminence, and of late has given concurrence to six universities/institutes.

In spite of such pro-active initiatives by the state, leading educationists are unanimous that there is crises in management of higher education as regulators are using tools of yesterday.

12. Accreditation, Ranking and Quality Assurance

Quality has been viewed as fitness of purpose, conformance to standards, value for money, relevance, perfection and consistency, depending on institutional vision and mission by different stakeholders in higher education. When quality is perceived as a continuing march towards excellence, it becomes an important attribute of scholarship. Some people view quality as a 'relative concept'. Some scholars say that if higher education is made available by opening a new college/ university in a region, which was deprived of it hitherto, quality has one meaning. But for a metropolitan society where such facilities have existed for long, quality would be judged by the availability or otherwise of the latest technology-assisted learning environment and one that promotes critical thinking, helps build reflective capacity and independent learning. In many countries, the responsibility to check for quality assurance in teaching, training, scholarship and research is vested in specialised agencies. But in India, public funded regulators evaluate the quality of conventional institutions/ programmes. As such, the system is over-regulated and multi-layered and dominated by dysfunctional bodies.

For enhancing the quality of higher education, the central government has established various assessment agencies, prominent among them being the **National Assessment and Accreditation Council** (NAAC) of UGC and the **National Board of Accreditation** (NBA) of the AICTE. These agencies acted as autonomous organisations to assess and give a grading to colleges and universities based on which students could decide the value of a HEI as also the UGC and state governments could decide their funding support. Under resource constraint, both agencies have done commendable work, though they could not comply with the pressure of accrediting all institutions. Further, it was realised that the assessment and ranking methodology and other processes have largely been ignored (rather could not handle) the 'process' variables in teaching-learning and assessment, which are the foundation for any quality paradigm and institutional ranking. Of late, the NAAC process has undergone a gradual change to comply with the National Institutional Ranking Framework (NIRF) – an institutional ranking by the government (besides assessment and accreditation by UGC) – the decision of which has been an outcome of the world ranking of higher education institutions.

In the case of QS ranking in which 959 institutions were ranked (out of 4,300 considered), the variables included academic reputation (40%), faculty-student ratio (20%), citations per faculty (20%), employer reputation (10%), international students (5%), and international faculty (5%). These are indicators that any HEI in India could consider and examine if one stands solid on these grounds. On analysis of the actual data for QS world ranking [25] of top 500 HEIs in 2014-15 showed that India did well for academic reputation and employer reputation, but the danger areas included: faculty-student ratio, and international faculty ratio. Not surprisingly, therefore, India had only four institutions in the top 400, while China had 11, Australia 21, UK 48, and USA 102 (FICCI, 2014) [26].

Concluding Remarks

The *Approach to the Twelfth Five Year Plan* (2012-17) (GoI, 2011) [12d] underlined its goals as follows: shift of focus to quality, more resources and better utilisation, enhancing employability, encouraging private participation, research culture, ICT, and multiple and strong independent accreditation bodies. Critical reflection is required to evaluate sincerely whether all the above goals have been achieved, especially when we have completed the plan cycle. The analysis presented in this chapter shows that notwithstanding sporadic interventions toward improving the quality of higher education by the government of the day, what is required is a systemic overhaul of the sector, especially in respect of quality teaching-learning and research, integrated use of technology-enabled education and training, and allied continuing professional development. This is core to the pyramid to which all other dimensions, including governance, funding and regulation are supportive. The recent government interventions toward reforms in Higher Education (HE) are welcome but sporadic, which implies that holistic vision is required to overhaul higher education in the country. This, in fact will bring in a more holistic entire education system in which higher education occupies a major chunk. These are expected to be addressed in the National Policy on Education which is under formulation and which might result in drastic reforms in the higher education sector for at least a few decades ahead.

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Chapter 2: STEM Education in India – Status Report and Perspective

[Science] is more than a school subject, or the periodic table, or the properties of waves. It is an approach to the world, a critical way to understand and explore and engage with the world, and then have the capacity to change that world...

– President Barack Obama
March 23, 2015

1. Science in India – Background

The prosperity of a nation is defined by the quality level of its educators, researchers, innovators and the vision of its academic leadership.

Historically, the Indian subcontinent has been a strong and vibrant hub for abstract intellectual activity such as the disciplines of philosophy and mathematics. Research is well-knitted in our traditions, leading to a strong culture of observational and applied sciences like astrophysics, material science, medicines, etc. Heavy contents of intellectual rigour, strong foundations of scientific thoughts getting translated into innovative engineering and technology, is more than evident in areas like architecture, urban planning, water harvesting technologies, warfare technologies, pharmacy, surgery, etc. This traditional strength has enabled us to have scientists like Srinivasa Ramanujan, C.V. Raman, S. Chandrasekhar, S.N. Bose, Homi Bhabha to name a few in modern times. Somehow, in the post-independent era, we have failed to connect and integrate our indigenous wisdom, traditional, and cultural strengths into our developmental strategies, and take leverage to advance our scientific and technical capabilities. Apart from some spectacular research achievements in the field of nuclear technology and space science, there isn't much to talk about that is emanating from modern India. There are a very few islands of excellence in the vast sea of mediocrity. The higher education sector is perhaps the most important engine of development in modern times. There appears to be a direct correlation between the developmental index and the penetration of STEM education the world over.

During the 1990s, with the opening of the economy for global integration, the job demands for engineers and technologists coupled with the discipline of management – the so called IT boom, witnessed the mushrooming growth of engineering and technical institutes.

Subsequently, Indian investments into basic sciences suffered – both in terms of resources and quality of students. With relatively fewer students opting for core engineering subjects and practically no student opting for fundamental sciences and mathematics-oriented/driven disciplines, the culture of research and innovation was worst hit. This trend continued till the depression of 2008. With realisation dawning on the government in the 21st century, several new measures and policy interventions have been planned to support basic science research. Some of the research and development initiatives which have since been launched are as follows:

1. Formation of the Science and Engineering Research Board.
2. Launch of the programme 'Innovation in Science Pursuit for Inspired Research' (INSPIRE).
3. Establishment of 10 Indian Institutes of Science Education and Research (IISERs) and new IITs, and 16 Central Universities.
4. Establishment of the Institutes for Nano-Science and Technology, the National Agro-Biotechnology Institute and the Translational Research Institute and proposals for setting up five other major research institutes as centres of excellence.
5. Mounting of the Biotech Mission (1998) and Nano Mission (2002).
6. Institution of several novel fellowships, including launching of Welcome Fellowships.
7. Institution of performance-related incentive systems.
8. Special package for science education and research in the northeastern region.
9. Establishment of a national spatial data infrastructure.
10. Start of 'Science Express' to attract young people to research.
11. Stepping up international S&T cooperation at an annual growth rate of 20 percent.
12. Launch of the 'Promotion of University Research and Scientific Excellence' (PURSE) programme.
13. Expansion of the 'Fund for Infrastructure Strengthening of S&T' (FIST) to include autonomous colleges.
14. Scheme of cognitive and security technology initiatives.
15. Creation of mega science facilities including the establishment of an 'Indian Beam Line', LIGO-India, ITER, INO, etc.
16. Small Business Innovative Research Initiative (SBIRI).
17. Protection and utilisation of public Intellectual Property right.
18. Opening the private sector for university research-level education.

However, despite these well-meaning efforts, integration of STEM education is still distant from making a significant contribution to existing industries and to frontline researchers. There are a large number of research institutions providing advanced learning and research courses, leading up to Ph.D. degrees in branches of science, technology, agriculture, social sciences, languages and other disciplines. Many of these institutions come under the umbrella of the Council of Scientific and Industrial Research (CSIR) and the Indian Council of Agricultural Research (ICAR). Even though a few of these national research institutions are referred to as islands of excellence, the overall impression about the quality of their research, output and performance has been not perceived to be good. There is a huge shortage of doctorates that is significantly impacting research and teaching in the higher education sector. Institutions like the IITs are currently facing a faculty shortage of around 41 percent, while there is a 40 percent faculty vacancy in central universities.

2. STEM India: Tackling Lack of Scientific Temper

A vibrant and progressive society is characterised by creativity and innovation in every sphere of life, be it the arts, crafts, engineering, science or any other scholastic activity. Without creativity and innovation, societies tend to stagnate and start degrading slowly. They become dependent on other societies for new ideas. This is true for any human activity, but more so for science and technology. Creative energies of individuals in society are free and formless. These need to be given expression and direction with respect. In the Indian context, examples of classical music and poetry are instructive. These disciplines require years of hard training and honing of skills. Though pursued by a small percentage of people, our society has recognised these as important activities, and has evolved a system to impart necessary training and developed and created a competitive environment for showcasing and rewarding talent. It is remarkable that these activities have survived various historical upheavals, types of rulers and forms of government. There has been constant development and innovation, shaped by socio-historic forces. As a result, Indian classical music and Indian poetry have a unique place in the world of art and literature. In spite of ups and downs, they are self-sustaining, robust traditions that do not require any outside support.

However, the same cannot be said for science and technology in India. We are heavily, sometimes completely dependent on developments taking place elsewhere. With very little to show as original, our status in the world of science and technology is that of 'takers' and not 'givers'. It is not as if there is any lack of basic temperament. The answer to this lies in the current state of affairs in STEM education itself.

It is an open secret that in India, present day science and engineering education has been unable to produce quality workers to address the problems facing the nation. The solution to these problems cannot be imported. We need an out-of-the box approach to address these problems. STEM education is the foundation for such a high degree of creativity and a culture of innovation. Therefore, a comprehensive re-evaluation of our higher educational system is the need of the hour. There seem to be many reasons, often complex, for the educational system's inability to foster creativity and innovation. We try to point out some of these reasons below and offer possible remedies:

2.1 Non-recognition of Science as a Cultural Phenomenon

A casual glance at the history of science in developed nations will tell us that science is a socio-cultural phenomenon and has taken hundreds of years to achieve the prestige and status it enjoys today. In the early days, eminent scientists were tortured, arrested and even burnt alive. Science was a peripheral activity, mostly regarded as witchcraft. It had to struggle for centuries, modifying and evolving, and about 400 years ago the tide began to turn in its favour. Even after that, science has always reflected the times and culture, and this process continues till date.

However, in its present form in India, science has been seen as an offshoot of the British education system and remains more or less the same even today. The intellectual tradition that we earlier had was displayed in philosophical enquiry of which scientific and mathematical enquiry formed but a small part. As an independent nation our leaders emphasised the importance of scientific temper but failed to recognise historical and cultural impediments, especially the fact that it would take many generations before science truly became a part of our cultural heritage. The education system must recognise science as a cultural and creative activity that is at par with other creative activities like music and poetry, and allow time and space for its growth without expecting quick results, as a long term investment in society. Training in science should ideally result in inculcating a way of thinking which will showcase itself with new ideas and innovations. However, we teach science and mathematics to a very large number of students, irrespective of their natural inclination. This necessitates designing the courses in such a manner so that everyone is included. Our present day educational courses become diluted to the extent that even essential and basic concepts are not passed on effectively. Standards continually decline and despite a high number of students joining science courses, there is an acute shortage of original thinkers. In comparison, we do not teach music and poetry to everyone; only to the inclined and talented, thus, maintaining rigour and standards. The same should be done for science.

2.2 Lack of Philosophical Basis of Science in Present-day India

According to *Bertrand Russel* [1]

> *Philosophy is to be studied not for the sake of any definite answers to its questions, since no definite answers can, as a rule, be known to be true, but rather for the sake of the questions themselves; because these questions enlarge our conception of what is possible, enrich our intellectual imagination and diminish the dogmatic assurance which closes the mind against speculation; but above all because, through the greatness of the universe which philosophy contemplates ; mind is also rendered great and becomes capable of that union with the universe which constitutes its highest good.*

Each sphere of human activity has philosophical foundations. There is a philosophy of life, art, business and markets, statecraft, war and peace. Interestingly, having no philosophy or having no faith in any philosophy is also a philosophical stand. There is simply no escape from philosophy. Science does not exist without philosophical underpinnings. Almost every university in developed nations has a Department of History and Philosophy of Science. It helps to understand science from a socio-historic and philosophical perspective, and to modify the practice of science continuously. In India, there is gross neglect of philosophy in the teaching of science. There is a tendency among the lay public and policymakers to see science as a finished product to be used for mankind. In fact, science and technology are ongoing intellectual adventures. The human mind is expanding its scope over the millennia and that is a biological evolutionary process. There aren't and never will be any final answers, because each answer will give rise to a host of fresh questions.

Also it is important that distinction must be made between science and technology. The goal of technology is to provide solutions to problems in such a way that it a) opens up new modes of communication and production; b) enhances ease of operation; c) lowers cost of production; and d) saves time. On the other hand, the business of science is to provide explanations of natural phenomena. These explanations may or may not serve technology immediately, but an expanded understanding would surely help in new invention and innovation. To be able to see present day science and technology in the biological as well as the socio-historic context is the job of philosophy. India has a rich philosophical tradition which unfortunately has been neglected in a most thoughtless manner. There are some very interesting connections between the Hindu, Buddhist and Jain schools of philosophy and modern day science. These philosophical traditions are entrenched in our society and daily life. The appreciation of the parallels and opposites between the ancient and the modern increases the understanding of the present and encourages participants by connecting their work with their day-to-day lives.

2.3 Neglect of Observation of Nature in Science Education

The observation of natural phenomena is the bedrock of scientific thinking. Even a cursory look at history reveals that from very early times, careful observation of nature has resulted in the formulation of laws of science. Extracting a law of nature is essentially a process of simplification and abstraction. It is true that nature is far more complicated than the cut and dried list of laws and formulae. The list also gives the impression that science is a finished product. True understanding begins with recognition and an appreciation of complexity, and the desire to simplify it. Most problems are not easily susceptible to the application of formulae. Most of the education in science in India relies heavily on rote learning. The objective type question and answer format does not encourage observation as a basic requirement. There is almost no desire to observe nature and connect it to scientific explanation. Students learn formulae and apply them to solve numerical problems, but do not appreciate how these formulae have been arrived at by the meticulous and sustained observation of natural phenomena. The gap between observation and theorising is seen more in urban areas. Rural and tribal societies are much more observant than urban societies which tend to rely heavily on existing theory. This disconnect is probably the root cause for the lack of innovation.

2.4 Neglect of Pictorial Thinking in Science Education

There is far too much emphasis on mathematical thinking and training. No doubt good science is characterised by mathematical rigour, but not while neglecting pictorial thinking. History tells us that the best of science and innovation has come about via pictorial thinking. Thinking in terms of pictures, making one's own pictures about nature and its complexity, and constantly modifying and improving those pictures, is the correct and exciting way of doing science. Mathematical rigour comes later and only after you know what to mathematise. Development of pictorial thinking and observation of natural phenomena go hand-in-hand. More the observation, the more accurate is the picture and the better is the ability to make connections with other things. Inter-disciplinary understanding cannot be achieved without observation and pictorial thinking.

2.5 Prevalence of 'Copy-cat' Research in Science

Unfortunately, the research done in India is invariably an extension of research being done in advanced countries. Students go abroad, join some ongoing research programme, come back to India and continue doing the same throughout their lives. Thus research does not get connected to problems – intellectual and/or physical – that are thrown up by our society and lives. The ideological allegiance to western science just makes us camp followers. We forget that their ideas are the result of hundreds of years of intellectual history. Those are their problems and there is no reason for us to work on those while ignoring our own. Dogmatic acceptance of western science and blind faith in reductionist rationalism results in second rate work. Knowledge gained in cultural isolation and without philosophical underpinnings is not only incomplete and shallow, but can also prove to be dangerous. Let us certainly learn from the West but not follow them blindly.

3. STEM India: Status, Relevance and Importance

Though leading edu-experts the world over have realised that STEM education is the need of the hour, does it hold relevance for India? India has the highest number of students in the world but there is still a huge gap between the skills offered and industrial demand. The reasons for this discrepancy could be many i.e., lack of academic infrastructure, innovative and interactive course methodology, qualified teachers, etc. [3]. Official data shows that less than one per cent of students pursuing higher studies choose research-oriented courses [4]. Offering a promising solution to this grim scenario, STEM education is emerging as the new face of futuristic education. Since 2012, with the advent of STEM education in India, science and technology has got a fillip [5,6]. STEM education generates quality educators, scientists, engineers and researchers capable of handling real life problems and there is no dearth of problems that await solutions in India, from intellectual to strategic, basic to generic, local to national, individual to collective, natural to man-made, etc.

STEM education has the power to change/transform 'the way we think' and the impact is long term, and forms the basis of all innovative R&D. It is just necessary to revamp the entire STEM education setup to transform from a 'knowledge delivering system' to a 'knowledge creation' mode. We have to nurture our young generation to think deeply and well so that they become innovators, educators, researchers and leaders who can solve pressing challenges facing our nation and the world today and tomorrow. The real strength of the youth lies in having strong scientific temper, intellectual content, fascination and being imaginative rather than looking for 'quick-fix' solutions to the problems/social issues. The inculcation of 'scientific temper' would surely translate the *jugaad culture* (one of our strengths) into a 'culture of innovation'. A strong sense of philosophy is also to be inculcated in the graduates.

Indian Prime Minister Narendra Modi's 'Make in India' enterprise that aspires to transform India into a major global manufacturing hub is going to increase pressure on the country's scholastic establishments, especially in the science, technology, engineering and mathematics fields to stir out exceedingly well-trained graduates [7]. This indirectly indicates that educational institutions will now have to focus on training their graduates in the latest developments in science and technology to make them capable of penetrating the STEM workforce. The 'Skill India' movement which plans to create this trained human capital pool requires support from every nook and corner of the country, similar to the American model [8]. The drive also throws open a new set of challenges for introspection on the STEM workforce of India.

What differentiates STEM from our conventional streams of education system is the fact that it does not advocate teaching-learning through textbooks and assessing learner's knowledge through marks-based assessment. It is a modern day approach that advocates the use of innovative curricula that discourages rote learning, and instead, creates students' interest in the learning process through innovation and practical applications to daily life. Hence, by exposing students to STEM and granting them prospects to examine STEM-related concepts, they will build up an excitement for it, and hopefully, practice a job in a STEM field. A STEM-based programme is enriched with real life circumstances to assist students to discover. STEM activities invokes hands-on and minds-on training [9].

Structuring the foundation of scientists, engineers and the next generation of innovators demands trained and passionate science teachers with appropriate skills and knowledge to inform, instigate and inspire learners. However, the demand for science educators continues to exceed supply by far. The STEM gap in India is significant and it is essential to bridge the gap through teacher capacity building and quality education resources. Students should be better-equipped to think deeply and well. This will give them opportunities to be innovators, educators, researchers and leaders. Today, some scholars view these disciplines as springboards for their careers. It is essential to close this gap and foster a critical spirit of scientific temper and innovation.

4. Culture of Innovation in the STEM Environment

In India, STEM education is a relatively new term and has drawn attention rather late. Contrary to the belief that India produces the highest number of scientists and engineers, the growth of STEM education in the country has been slow until recently. Thus, some general observations and suggestive system interventions to reduce the gap discussed in the previous section can be as follows:

1. To strengthen the nation's scientific capacity, a few universities can

be selected to strengthen pure fundamental research.

2. To expand the participation of science and research, the process of knowledge transfer can be augmented by forming participative mechanisms between fundamental research-based universities, enterprises and technological higher learning institutions to improve technology implementation and its use for the betterment of society as a whole.

3. Higher education institutions at all levels should have a clearly defined structure, mission and tasks to ensure that diverse education needs of individuals are met in a globally competitive fashion.

4. India's higher education needs to open itself in terms of international exchange, collaboration and cooperation. Ideas and innovation can flow by bringing together people from different backgrounds, disciplines and regions through collaboration. The government needs to put policies and frameworks in place to build more and more collaboration and talent exchange programmes with international universities to ensure that our scholars are involved in peer learning, creation and dissemination of new knowledge.

5. As a nation, we can learn considerably from higher education reforms in China and ensure that rapid expansion of higher education initiatives does not result in higher education massification minus quality. Hence, an appropriate balance needs to be maintained in higher education growth, funding, teaching resources and infrastructure, and enrollment.

6. Equity is also of prime importance in the distribution and expansion of local and regional higher educational institutions in India. The government needs to ensure that resources are distributed equally between urban and rural higher educational bodies. Further, the overall national capital expenditure per student also needs to be rationalised to ensure overall harmony and sustained development of the higher education system in the country.

7. Along with structural changes, the academic programme and curriculum also requires transformation. The current curriculum promotes rote learning, and thus, fails to meet the demands of a technologically-inclined society as well as learners.

8. A mass and quality-based technology-oriented higher education system calls for a self-sustaining, robust higher education financing system. Enrollment growth in a technology-driven curriculum shall result in more per student expenditure. Hence, in this case, keeping in account the affordability, a justifiable cost-sharing scheme has to be adopted and implemented to ensure access and opportunity for all, irrespective of economic background.

9. Generating STEM-based employment shall remain another important national challenge.

Furthermore, a few specific observations and suggestive system interventions that may work, are briefly discussed below:

4.1 Innovative Learning Aids in STEM

An innovative learning culture in STEM can be inculcated if a comprehensive approach of 360 degree holistic development focuses on new and intuitive ways of classroom engagement. Pre-requisites for this approach revolve around the following components:

1. Enhancement of critical thinking skills. Apart from classroom concept flow, critical thinking and assessment forms the basis for analytical reasoning. Such skills are the foundation of problem assessment which lays the basis for logic building.
2. Authentic case modelling. Cases and problems more realistic and relatable in nature can ignite intuitive thought flow that helps students relate to what they are studying.
3. Learning by individual research and trial and error basis. Getting hands dirty with hands-on stimulations will make students learn from their own experience and better train their logical model.
4. Collaboration with social skills. Social skills are a formative base for the development of emotional intelligence faculty, which today is considered more powerful than the intelligence quotient faculty.
5. Hard work and a tenacious approach can never be replaced by any amount of automation and those basic needs have to be set right.
6. Enriched and not accelerated experiences are the need of the hour. In-depth knowledge of core concepts is the key to innovation.

4.2 Few Ideas for Inculcating Innovative Strategies in STEM Education are as Follows:

1. In India, the majority of education happens through a lecture based system which is a uni-model method of teaching. Project-based assignments are limited and suffer from plagiarism. Students fail to pick up real-time projects and ones which they can relate to. As a result of which, the required zest to produce something novel suffers. Each student can be advised to pick up a problem from his own life and automate it/develop utilities for it. Extensibility will only prevail when context is use-worthy.
2. Inclusion of case work covering real life industry examples, in-class quizzes, guest lectures from industry veterans, industry projects (through a tie-up with corporate firms/startup bodies), group projects analysing a real-world problem, individual assignments, pre-class readings are some possible ventures.
3. Case work and pre-class readings are picked up from real-world examples (for e.g., how Flipkart uses machine learning techniques to offer product recommendations). Pre-class readings could be picked from news articles and research papers. These readings should emulate core course concepts, most of which the student can easily

grasp by themselves. The lectures should deal with discussing solutions on these readings and extensibility to advanced concepts. Applying concepts to relatable concepts is the crux here.

4. Encourage in-class discussion because a wealth of knowledge lies with students. Converting the instructor directed questions of the students to open house class discussions will not only expand the horizon of seekers, but also provide effective classroom engagement for the rest.

5. Course grades must be divided amongst these learning methods. For e.g., 50% end semester examination, 10% class attendance, 10% class participation, 10% in-class quizzes and 20% project work. A greater bifurcation of internal marks needs to be divided across the semester subject engagements rather than promoting the idea of last minute studies for the heaviest weighted examinations. This way, students will move along with the instructor right from the beginning as well as understand all concepts thoroughly, thus eliminating the need for last minute mug-ups.

6. Show relevant YouTube videos in class. Any concept that needs demonstration of algorithm can be effectively explained through a 3D emulation of learning, rather than leaving room for imagination in the pupil's mind. Grasping power varies at an individual level, and hence, all students are not able to run at the same pace as the instructor in comprehending a sequential concept. This way all students can focus on a clear picture of emulation of the algorithm and grasp quickly.

7. Encourage individual and group presentations. Lab assignments should be custom designable for every student, so that they can simultaneously inculcate the core concepts into their group projects and presentations. Peer reviews, pair programming are some other methods of promoting collaborative learning.

8. Building a simulations software – students input values and software generates different results based on input. Students get to see how changing the input impacts the result.

9. Flexible learning spaces help stimulate situational thought flow that builds up problem solving abilities. Realistic venues, outdoor engagement, industrial space experiences can give them a more relatable experience of how things are done.

10. Grand challenges that can bring together diverse thought processes on implementation of real-life tech solutions are a great way to stimulate collaborative learning through peer coding and constructive feedback.

11. Dedicated communities of practice and learning are another way to engage students in community work environments. In Pittsburg, 'Remake Learning' is a group of over 250 innovators and educators working together to leverage resources for innovative teaching-learning.

There is already so much content (full semester courses), especially in STEM subjects available online (MIT Courseware, Coursera). These courses are taught by world class professors. All assignments are built into the course. Why not use this resource inside the classroom? That will solve the challenge of finding industry experienced teachers. Instead, we can have a facilitator to just answer student queries.

5. Strengthening STEM Education

It is worthwhile to consider briefly some specific and successful case studies and efforts that have been tried to strengthen STEM education. The National Science Foundation (NSF), in the United States is the central organisation that frames plans and course of action in the STEM field [7]. National Aeronautics and Space Administration (NASA) also implements courses and curricula to progress STEM education in order to refill the pool of scientists, engineers and mathematicians who shall lead space discovery in the 21st century. The Florida Polytechnic University is also dedicated to STEM education. In 2006, President George W. Bush announced the American Competitiveness Initiative to tackle under-performance in central government aid for educational growth and development at all educational levels in the STEM field. The NSF Foundation also has several programmes in STEM education, some even for K-12 (a term used in education and educational technology in the United States, Canada, and possibly other countries. It is a short form for publicly-supported school grades prior to college. These grades are kindergarten (K) and 1st through 12th grade) learners. In India, STEM education is the need of the hour to help learners make the transformation from users of technology to innovators. This can be majorly achieved through:

5.1 Technology Supported Learning

STEM education often uses new technology to increase learner interest in STEM fields. Technology-supported learning can help eliminate conventional content delivery and catalyse development of a broad mix of skills among learners [10]. It can catalyse the development of higher order thinking skills among learners while improving actual learning outcomes. Varied technology-driven innovations in STEM education are being adopted in some schools. However, their success in instructional practice is decided by accessibility to technical resources and the support they depend on [11, 6]. Further, in a diverse country like India, they also require to be attuned with the local perspective and educational configuration available. It is also significant to supply adequate professional growth, administrative and political support as well as time for execution [27].Instructors, strategy makers and other stakeholders should also stress on a budding stratagem to make it possible to embrace technology-enhanced advances in STEM education, while deliberating on the following issues:

1. **Knowledge of new models.** Effective usage of technology-enhanced educational models relies on awareness of their being. For example, many tutors or policymakers do not know that online virtual laboratories can also be used with similar efficacy as material laboratories.
2. **Over-estimation of the complication.** Technology-enhanced teaching models

may have an overtone of complexity that may stop certain teachers from their adoption. However, virtual association does not necessarily demand very complicated technology. Likewise, the use of certain online laboratories may only necessitate access to the Internet. The opinion that technology-enhanced learning is hard may lead to teachers' lack of interest in technology, or in the models that they sustain.

3. **Equipment and funds.** A major roadblock to the use of technology-enhanced learning lies in the lack of basic apparatus that still typifies many schools in rural India. The absence of basic operational funds for such schools to purchase digital resources and devices may also deter the widespread adoption of STEM practices. Further, in spite of their rising number, it would take far more online remote laboratory experiments to see them become part of mainstream Indian education.

4. **Compatibility with educational structures.** In most cases, the inventive character of the educational models may make them hard to implement in actual educational framework. For example: the compatibility of the online laboratories of Amrita University with the Indian National Curriculum and the review of its contents by relevant authorities are a major factor in influencing their large-scale adoption. Further, the lack of professional development; both formal teacher training as well as peer learning further contributes to difficulty in adopting innovative learning tools. Even at the development stage, providing professional development is a key factor for success for the successful implementation of a teaching model. As these models spread beyond the early adopters, it becomes even more important that they are accompanied by enough resources for teachers to get timely formal or informal training. As a new development of the Catalyst Initiative, Hewlett Packard launched Catalyst Academy in 2013 to provide online learning experiences for teachers.

5. **Administrative and political support.** Appropriate support from contemporaries, be the other teachers, institute law makers, administrative or technical staff, or external stakeholders, are also vital for embracing new technology-based pedagogies.

5.2 Adequately Trained Human Resource

To successfully adopt new models of technology-supported learning also requires teachers and educators to revisit their pedagogy. This may prove a big challenge. The effectiveness of a technology-supplemented education model is not from technology alone, but from the support it requires. In the absence of adequately trained pedagogic resources that lack understanding of how to use technology, it might fail to foster a deeper learning for expected outcomes. Real-time formative assessment shall enable educators see what students think and know but for this they still have to use this information in their teaching to encourage students to reflect more deeply and challenge their misconceptions. Experiential learning is most likely to provide expected improvements in conceptual understanding and scientific inquiry skills if teachers encourage students to repeat their experiments and provide learners with a vigorous platform to appreciate them. Further, the implementation of latest technology-supported teaching-learning models are most likely to be accepted and supported by educators when there is adequate support from policymakers. Ample technological infrastructure and availability of a critical mass of educator-friendly digital resources are indispensable for large-scale successful STEM adoption.

5.3 Reorganisation of STEM Education

To enhance learning outcomes and promote development of higher order learning skills among students, we need to expand the array of learning opportunities offered. This can be realised by launching technology-supported academic models into curriculum like gaming, virtual laboratories, international association, real-time decisive evaluation and skill-based appraisal. Their potential realisation is meticulously detailed below:

1. Educational Gaming: This can help develop content understanding while inspiring critical thinking as well as imbibing ingenuity among learners. Here learners can be introduced to video games, simulations or virtual worlds based on fantasy or real-life. It may also embrace mutual project-oriented learning experiences where learners themselves can be game developers and content producers. The model may further encourage:

   i. Learning by doing: The interactive, reactive and collaborative nature of educational gaming enables learning by attending to complex topics, by allowing students to make mistakes and learn from them. This strategy can particularly be useful when educating professionals who require the capacity to think and work simultaneously like architects, engineers, chemists, physicists, doctors, nurses or carpenters.

   ii. Student engagement and motivation: Based on play and increasing challenges, educational gaming can foster student engagement and motivation in various subjects and education levels. Low-achieving students may find the educational gaming experience more engaging than high achieving students. Students' motivation increases more when they construct games themselves as opposed to just playing an existing game.

   iii. Students' thinking skills: Games contain the potential to motivate students find novel ways around problems and application of knowledge, in novel ways and 'imagine like a qualified professional'.

Educational gaming may hence advance learners' skills like problem solving. Different real-time projects demonstrate the benefit of diverse types of educational gaming for developing varied innovative skills. For example: The National University of the United States created and validated a learning approach based on game design for higher education students. The City Academy Norwich of the United Kingdom also implemented a virtual world simulation to instruct middle school students the entangled associations between energy requirement, economics and the environment. Since 2010, the National University has been scaling up, validating and further developing its Game Design Methodologies (GDM) and related resources.

1. **Online laboratories:** Remote or virtual online laboratories, are an additional hopeful advance to improve instruction and learning of STEM at all levels of education. Virtual online laboratories permit students to replicate scientific experiments, while remote ones permit students to use real laboratory equipment from a distance through the Internet. Instructors and policymakers should promote online laboratories to enhance access to a variety of experimental learning. As a major advantage, online laboratories allow students and teachers access to a wide range of equipment, which is impossible for an average school. Further, remote laboratories can also enable students the right to use expensive equipment. Online laboratories are thus an apt complement to school science labs through just an Internet connection. In 2013, there were 907 online remote high school laboratories listed globally on i-Lab Central (www.ilabcentral.org), a web gateway. These laboratories offered remote access to equipment such as neutron spectrometers, radioactivity equipment, and equipment for measuring electronic circuits and devices. There were plans for public access to heat exchangers, inverted pendulums and shaking tables, but the small number of resources currently available limits wider adoption. Virtual online experiments are more numerous on open educational resource platforms. Online laboratories can be expected to offer the following benefits:

   i. Lower-cost access: Online laboratories may help overpass the digital divide by providing students with faster access to experimental learning at a relatively low cost. Simulations may prove to be of lower cost than experimental hardware, although 'little empirical data exists on the actual cost of providing online laboratory'.

   ii. Flexible access: They can permit elastic access to practical experiments, allowing for improved learning time that is not attached to a specific timetable or setting.

   iii. Student learning: Online laboratories can further sustain student indulgence and attainment as well as physical hands-on learning.

2. The power of online laboratories has been illustrated through the North Western University, United States. They have developed assets for an online, distant radioactivity laboratory to enable students to discover definite concepts in biology, chemistry, mathematics and physics. Amrita University, India, has also developed

online laboratories (OLabs) for upper-secondary physics and mathematics. Amrita University further aspires to extend its Online Laboratories (OLabs) and associated assets to 50,000 upper-secondary science students. By 2012, 36 schools and more than 9,000 students in Kerala, had registered with OLabs.

3. Collaboration through technology: It can augment students' communication, commitment, knowledge and opinion, while enhancing flexibility and variety in educational knowledge. Technology-supported collaboration can further augment students' knowledge of universal challenges and widen their appreciation of other cultures. Instructors and policymakers should use technology as a means to augment collaborative learning across long distances and between diverse cultures. Policy makers can facilitate this by augmenting platforms for international exchange among schools, teachers and students. Exchange can also be supported through cloud computing, video-conferencing or online platforms. These new technologies make international alliances much easier than in the past.

4. For example, learners and teachers at the Scofield Magnet Middle School in the United States and at the Shandong University Middle School in China teamed up on a water quality project with support from scientists and other professionals. While American students scanned the value of their local groundwater, Chinese students investigated the Huangshui River Basin in China. Students calculated water quality, geography, drainage, vegetation and fauna, besides impact of urban growth on water quality. Technology enabled students in both nations to evaluate and replicate their findings on the water quality and to augment their knowledge of other cultures. As a hopeful form of STEM education, collaboration through knowledge and vice versa may develop:

   i. Flexibility: Knowledge enables students to team up and perform at 'their own speed', beyond the official classroom hours and without restrictions of physical setting.

   ii. Cultural diversity: Technology can appreciably augment potential for inter-cultural relations by augmenting the extent of collaborations to distant locations, even across borders.

   iii. Student interaction and engagement: Technology-enabled cooperation can persuade student group work skills, communication and meeting. Yet, 'active learning strategies' are not robotically adopted and may vary across cultures.

   iv. Students' thinking skills: Online collaboration may augment higher order thinking even more than face-to-face cooperation through 'more intricate and more cognitively challenging discussions'.

For example: Coventry University has paid attention to mutual project-based education involving British and Canadian architecture undergraduates. The learners use virtual collaboration for scheming a construction, including costs and plans.

5.4 Real-time Formative Appraisal Technologies

Technology drastically eases the use of formative appraisal – recurrent, interactive appraisal of student progress and understanding (OECD, 2005). Clickers, tablet computers and other types of technology facilitate immediate contact and reaction between teachers and students. Instructors and policymakers should consider the use of real-time formative assessment as a mechanism to facilitate more personalised learning. The instant reaction it provides allows teachers to customise their teaching as per the needs of each student or to particular groups. It further eases the involvement of each student in classroom discussions. As a hopeful educational advance, real-time formative assessment could augment:

1. Targeted instruction: It permits teachers to examine student learning as it occurs to better modify their teaching methods as per needs of individual students.
2. Student learning: It can also enhance student accomplishment by motivating students' expression about their needs in their own learning.
3. Problem solving and creativity: Real-time formative assessment offers possibilities for assessing types of activities and skills like problem solving or creativity – potentially enhancing achievement of these skills.

For example: The Colorado School of Mines Scheme allows science and engineering higher education learners to submit open layout inputs such as graphs or drawings to ensure rich and frequent student commitment in the learning process.

5.5 Skills-based Curriculum Alignment With Technology

Utilising technology for skills-based curriculum coalition can encourage a more precise appraisal of the range of skills included in STEM plus curriculum and standards. While it is becoming increasingly prevalent to build up such skills-based curricula, their final impact on authentic teaching and learning varies as per the accessibility of effectively aligned support systems. This is predominantly correct for student appraisal, but also for educational materials, teacher guides and professional teacher development. STEM plus skills, technology can be advanced through:

1. Adequate assessment: Technology can help gauge compound skills such as analysis or problem-solving through procedures such as essays, blogs or virtual learning environments. For example, Universidad de las America's, Puebla, Mexico has developed support systems with proper standards, learning environments and professional growth prospects for instructors as well as seminal and cumulative assessments appropriate for the development of 21st century skills. The courses plan to 'advance

student understanding of engineering methods, aptitude to solve practical problems and complete real-world projects' by emphasising problem-solving learning environments.

2. Collaboration between industry and academia should be promoted in STEM domains to enable appropriate support for innovation in fostering knowledge flows through new ideas and peer learning.
3. Mass Quality Higher Education Assurance: Like China pursues mass and quality higher education, the Indian governance model also needs to adopt a mass quality higher education assurance plan. For this, specialised bodies need to be implemented for providing scientific, systematic and standardised implementation and an evaluation plan for varied higher education imparting institutions [12].

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Chapter 3: Creativity and STEM Education – A Strong Interdependence

> *The need to be right all the time is the biggest bar there is to new ideas. It is better to have enough ideas for some of them to be wrong than to be always right by having no ideas at all.*
>
> – Edward D. Bono

1. Introduction

We live in times of autonomous cars, reusable rockets and artificial intelligence; we are still living in an education system that was set up for factory workers some 200 years ago. What we should be doing instead is to focus on skill building and setting any learner – be it in compulsory education or in lifelong learning – up for success. There is a need to understand and appreciate that creativity is an important part of being. It is integral to being a biologist, lawyer, historian, scientist or engineer. In fact,

> *creative energies of individuals in a society are free and form-less. They need to be given an expression and a direction and has to be nurtured with respect. – Suresh Garg*

On the other hand, the toughest issues facing our society are about providing citizens with adequate and affordable food, housing and health care, efficient and economical public transportation, and clean and safe energy. These are unlikely to be solved by conventional means – Had this been possible, it would have been solved by now. To the extent that problems are scientific or technological, creative scientists and engineers are needed to solve them, apart from a culture of scientific temper among the general public. Science is fundamentally a creative pursuit. Good scientists must know how to draw a connection between disparate ideas and disciplines. Paradigm-changing scientists (in the entire history of scientific and technological evolution) know how to look at old problems in a way that no one else has ever looked at them and create an idea that is entirely new.

In this regard, an initiative by the Department of Science and Technology (DST) in developing a scheme to get doctoral candidates in science programmes to publish at least one 'popular science' article explaining their research before they land their degree is greatly appreciated. While, it is true that many professional scientists and technologists have immense creativity, science education often lags in producing creative scientists. It is well documented that classes that emphasise rote memorisation and not an interdisciplinary approach can stifle scientific creativity. There is no use denying that our current education system mostly emphasises 'Conformance' in a big way, as compared to 'Creativity'. Some trends for change are visible in the global scenario when we find that the acronym STEM (Science, Technology, Engineering and Mathematics) is being replaced by

STEAM (Science, Technology, Engineering, Arts and Mathematics). This inter-alia implies that an interdisciplinary approach is a must for creativity.

In a recent book, Author Walter Isaacson brings out the point that **creativity ultimately is subject neutral.** He proves his assertion by demonstrating that the two men who revolutionised the world – Steve Jobs (founder of Apple – a great product of science and engineering) and Leonardo Da Vinci (the creator of Mona Lisa – the most admired portrait in the world) have a lot in common. According to Issacson, both Jobs and Da Vinci were able to marry art and science to create world-changing innovations. Beauty, design and engineering were all the same to them, Isaacson concludes that one lesson to learn from their lives is to embrace many fields of knowledge and the passion behind it. Just to emphasise further that it is far easier for scientists to be creative if they have an interest in arts also. An emotion-recognition programme developed by a great scientist, has analysed that Mona Lisa is 83 percent happy, nine percent disgusted, six percent fearful and two percent angry. The important observation here is that the scientist had to learn and appreciate the 10 universal laws of art which evoke responses in the brain.

2. Revisiting UNESCO Goals to Emphasise Creativity

By and large, India, as also most Asian countries, are perceived as 'consumers of western products'. This has not challenged us adequately for 'self-identity', 'self-interdependence', and 'prosperity'. Hence, our focus has never been to design education to yield creativity and productivity. It has now become necessary for us to revisit the following stated UNESCO goals of education as:

- Learning how to learn
- Learning how to do
- Learning how to work together
- Learning how to be

Rather, the following characteristics must be inculcated in people:

- Learning how to learn critically
- Learning how to do creatively
- Learning how to work constructively
- Learning how to be wise

To consider the role of creativity in students' learning and their experiences of learning, we have to be aware of basic assumptions:

- Being creative is inherently present in all disciplinary learning (although the word 'creative' might not be often used in descriptions)
- We all need to be creative (inventive/adaptive) in a world that is constantly changing – a world that requires us to adapt/change.
- While creativity is recognised as a central feature of identity in subjects like the performing arts and design, it is largely implicit in other subjects also. Teachers have always valued creativity, originality, flair and imagination in their students' learning.

Fostering creativity in education is intended to address many concerns: This is necessary to handle the VUCA (Volatile, Uncertain, Complex and Ambiguous) world.

It is only necessary to transform education, particularly science and engineering education to produce 'freely creative and original thinkers', as against the current inadvertent objective of producing 'conformists' and 'stereotypes'. Our education focuses on 'knowledge acquisition', which is necessary, but insufficient, as it is not possible to know what knowledge will be needed in the future.

3. Nurturing Creativity in STEM Approach to Higher Education

> *Equipped with his five senses, man explores the Universe around him and calls the adventure Science.*
>
> – Edwin Powell Hubble

There are a few known types of nurturing creative learning activities in science, which are discovery, understanding, presentation, application and transformation of scientific knowledge. Creativity can also be generated through scientific knowledge in various forms of expression. For example, knowledge, concepts and principles can be presented in the form of role playing, drama, music, pictures, poems and stories. To foster creative knowledge, students can be given a situation where they can find new ways to explain the phenomena of science, to make predictions, to solve problems, to state or imply that what is not known. **Students must be encouraged to ask questions and criticise any discipline of science and knowledge** in the text book as an alternative to develop methods and new ways to integrate them with creativity in science learning. A series of questions can be used to stimulate new ways of thinking about a process, plan or device.

1. *Adapt?* (Are there new ways to use this as is? Other uses if modified?)
2. *Modify?* (New twist? Change meaning, color, motion, sound, odor, form, shape? Other changes?)
3. *Magnify?* (What to add? More time? Greater frequency? Stronger? Higher? Longer? Thicker? Extra value? New ingredient? Duplicate? Multiply? Exaggerate?)
4. *Minify?* (What to subtract? Smaller? Condensed? Lower? Shorter? Lighter? Omit? Streamline? Split up? Understate?)
5. *Substitute?* (Who else instead? What else instead? Other ingredient? Other material? Other process? Other power source? Other place? Other approach?)
6. *Rearrange?* (Interchange components? Other pattern? Other layout? Other sequence? Transpose cause and effect? Change pace? Change schedule?)
7. *Reverse?* (Transpose positive and negative? How about opposites? Turn it backward? Upside down? Reverse roles? Turn tables?)
8. *Combine?* (Blend? Alloy? Assortment? Ensemble? Combine units? Combine purposes? Combine appeals? Combine ideas?)

Training has to be provided in asking questions, not just answering them, especially in advanced undergraduate and graduate teaching programmes. Many techniques have been suggested for exercising creativity and developing problem-solving skills in the classroom. In every course, some open-ended and under-defined problems should be assigned and more information than is needed should be provided for unique solutions. Problems should also be assigned that call for generation of possible alternative solutions, and, when the solutions are evaluated, credit should be given for *fluency* (number of solutions generated), *flexibility* (variety of approaches adopted) and originality.

In one instance, students in a graduate course in chemical reaction engineering were asked to make up and solve a final examination for the course. They were told that a straightforward 'given this, calculate that' examination would earn only a minimum passing grade and to get more credit, they would have to include questions that called for analysis beyond that contained in the text, synthesis of material from other subject areas and subjective evaluation. The results of this exercise ranged from acceptable to spectacular. Excellent questions were formulated covering every aspect of chemical reaction engineering and incorporating elements from chemistry, biotechnology, a variety of other scientific and engineering disciplines, behavioral psychology and several topics that defy classification. The students almost unanimously reported finding the exercise instructive and enjoyable, and many of them indicated satisfaction at discovering abilities in themselves that they had never valued or even knew they had. The exercise has subsequently been repeated twice with equally good results.

The basic philosophy needed is to produce teachers who can motivate students to think creatively and critically, and to reward those who demonstrate intellectual originality and academic honesty. A teacher who values originality can produce original thinkers. Society needs more original thinkers than parroting tinkers. Academic excellence (at least in science and engineering) is synonymous with skill at convergent production, since such an education, as on date, normally involves only problems with single correct answers. On the other hand, both convergent and divergent production is required to solve serious technological problems. A purely convergent thinker is unlikely to come up with an innovative solution when conventional approaches fail, while a purely divergent thinker will generate many innovative ideas, but may lack both analytical ability to carry them through to final form and evaluative ability to discriminate between good and bad solutions. If we as science and engineering educators cannot find enough individuals who combine these abilities at the very least, we should be turning out some who excel at one or the other. To do this, we must provide instruction and practice for both modes of thinking. In this respect, **we are failing abysmally in the educational experience we provide for our students** from the first grade through the last graduate course. Never (well, hardly ever) are words breathed for the following effects:

1. Some problems do not have unique solutions.
2. Some problems may not have solutions at all.
3. Problems in life, unlike problems in school, do not come packaged with the precise amount of information needed to solve them – some are over-defined, while most are under-defined.
4. Problems in life, unlike problems in school, are open-ended: there is

no single correct solution and any realistic answer invariably begins with, 'It depends....'

5. The more possible solutions you think of for a problem, the more likely you are to come up with the best solution.
6. Sometimes a solution that sounds foolish at first is the best solution.
7. To be wrong is not necessarily to fail.

As American psychologist Robert Sternberg said, '**Children are natural question askers**...but whether they continue to ask questions depends in large on how adults respond to them.' What's more important: getting the right answer or asking the right question? Thought leaders in various fields – from education to management to the sciences and the arts agree that asking questions is a fundamental part of thinking, learning, inventing and creating. As a famous educator said, '**All the knowledge that we have is a result of our asking questions**; indeed question asking is the most significant intellectual tool that humans have.' And Peter Drucker, management consultant and author, reiterated this idea when he said, 'The most common source of management mistakes is not the failure to find the right answers. It is the failure to ask the right questions.'

4. Identifying the Creatively Gifted

> *The sad fact is that teachers generally do not prefer the more creative students. Furthermore, they do not have much confidence in the future success of the more creative students.*
>
> – J.P. Guilford

The creatively gifted seem to resist being classified, which is exactly what one would expect of people who think in unique ways. Several instruments have been devised that are supposed to measure creative potential but no general agreement exists regarding their validity or reliability. However, studies suggest that certain traits are characteristic of creative individuals, including independence, inexhaustible curiosity, tolerance of ambiguity in problem definitions, willingness to take risks, persistence in pursuit of problem solutions and patience to allow solutions to take shape in their own time. The problem is that these characteristics are difficult for course instructors to spot, since they don't show up in conventional classroom activities. Other characteristics of some creative individuals are more easily recognisable, but unfortunately are apt to be viewed negatively. We do come across creative students whose course performance is highly erratic – very good grades in some courses, very poor ones in others. Other studies of creative individuals also refer to the possible presence of personality traits such as self-confidence bordering on arrogance, introversion bordering on misanthropy and indifference bordering on hostility directed at anything that diverts an individual from his or her immediate areas of interest.

The oddball makes us uncomfortable. The student in the next-to-last row, chin in hand, looking bored or apparently sleeping, who suddenly pipes up with the killer question that zeroes in on the flaw in our logic – our unstated assumptions, the exception we never thought of – is not someone most of us welcome in our classes with gladness in our hearts. Professors without high levels of self-confidence don't particularly want to see him coming and if there is a way to put him down or shut him up, they are tempted to grab it. Failing that, they go to the delay game: '*Good question, but we really don't have time for it now. I'll get back to you later*.' That is often the last anyone hears of it, unless, the student is pushy enough to come back with it.

Obnoxious behavior may in fact be the negative sign we take it to be. However, it could also be an indicator of the type of thinking ability needed to solve problems that defy conventional solutions. There are times when we are in unique positions to encourage or stifle creative individuals in our programme, such as when we advise students, assign grades in courses or projects and evaluate applications for graduate school. On such occasions, we might look twice at the individuals who display the traits we have been discussing, hunt for evidence of a creative spark in the erratic or socially unacceptable behavior with which they often confront the world and attempt to convince them that they have something unique and critically important to contribute. It is unfortunate, but true, that many creatively gifted students have never been told they are gifted; they only know that they are different and that their differences are socially unacceptable. It may take nothing more than recognition from a single professor to set them on the path to use their gifts for the rest of their careers and lives productively.

5. Creating an Atmosphere Hospitable to Creativity

Almost all researches useful to society have necessarily to be creative and inter-disciplinary (lots and lots of examples can be cited for illustration). A caution here for not adopting the usual approach in the country of adding a subject and/or modifying the curriculum. It is not the content which will have an overbearing effect, but the approach towards delivery of content that will be important. Very recently, two universities in New Zealand collaborated to launch an institute on 'Applied Creativity'. The underlying theme is that creativity cannot be taught, but creative skills can be honed. The institute is all set to begin its first academic session and will have a three-year undergraduate degree course called 'Bachelor's in Creativity'. To quote the institute, '.... (It) will have large open learning reconfigurable spaces, allowing students to interact and collaborate on projects which will encourage multi-disciplinary skill development and acquisition ..., also, will integrate academia with real-world opportunities and experiences for learners'.

If we study our Indian education systems of yesteryears, we do learn that in the history of education, knowledge was never compartmentalised the way it is seen today. So much so, we struggle to define titles such as: Chemical Physics, Physical Chemistry, Financial Engineering, Social Engineering, etc. This over compartmentalisation has led to the unintentional killing of creativity and innovation in youth to a good extent. We are making some efforts to revive it, but still not making use of creating a knowledge base from so many ancient scientific and engineering marvels. Also learning from nature, which was an essential built-in for yesteryear concepts is being given a go-bye at a very heavy cost, apparently.

What is then the correct way of teaching people to be, e.g., scientists

> *and engineers? It is quite clear that we must teach them to be creative persons, at least in the sense of being able to confront novelty, to improvise. They must not be afraid of change, but rather, must be able to be comfortable with change and novelty, and if possible, even to be able to enjoy novelty and change.*
>
> – Abraham H. Maslow

Perhaps even more important than providing exercises in creativity, is making students feel secure about participating in them. Most of us learn early that being wrong is unacceptable and looking foolish is even worse, and that these lessons are reinforced throughout our lives. Unfortunately, teachers are frequently the worst offenders in creating these fears and the child who is humiliated for asking a 'stupid' question or coming up with a 'ridiculous' idea or offering an 'obviously wrong' solution will wait a long time before sticking his or her neck out again. **If we are indeed to produce creative scientists and engineers, we should be offering classes where risk-taking is usually needed** to solve real problems and encouraged.

6. Creativity in Engineering Education

6.1 Engineering as a Creative Discipline

Engineering is the creative application of scientific principles. While manifestations of engineering creativity are overwhelming in everything that surrounds us, the nature of ingenuity and creativity remains elusive. Furthermore, it can be argued that today's education system neither promotes ingenuity not provides all the necessary tools to sustain it. **Engineering requires innovation, creativity and flair focused in a design process** … Design is at the heart of engineering and it is the domain, where professional engineers demonstrate their creativity and innovation. **Engineers transfer ideas and things from one context to another**. They adapt products produced for one market so that they can be used in another market. Extending the use of something is another dimension of the engineering creative enterprise.

Perhaps, there is something unique in the way imagination is utilised for access to domain specific knowledge and the skills of an engineer. Perhaps, there is also something significant about the **creativity in the way engineers are inspired to imagine,** by the technical problems they encounter and the economic constraints within which they work. Engineers have to solve problems often on the basis of limited and possibly contradictory information. In situations of incomplete data, the imaginative use of pattern recognition and predictions based on similar situations **must play a part in the thinking process**. **Engineers have to apply systems thinking to complex problems in order to think of the problem holistically** – how the components of the system interact and relate to each other. They must balance costs, benefits, safety, quality, reliability, appearance and environmental impact. Balancing so many variables in finding solutions may be a distinctive feature of an engineering problem and an important driver for creativity. **Giving students practice and feedback in solving open-ended problems** – helping them learn (a) to tolerate ambiguity; (b) that the good may be the enemy of the best, but also that the good is very often good enough; and (c) that failures are inevitable, acceptable and instructive stepping stones on the path to success.

6.2 Factors that Inhibit Creativity in Engineering Education

6.2.1 Related to teaching – what the teacher does

1. Too much time is spent on teaching details which are either irrelevant in an educational context or the knowledge that would be picked up in practice.
2. Reluctance of teachers to try fresh teaching methods as they require more time and offer no real promotional benefits.
3. Formal evaluation of teaching performance is good for ensuring that standards are maintained or established, but kills creativity, as those in charge are more concerned with procedures and less about education.
4. Having tutors or mentors who are not experts or who possess insufficient real practical experiences.
5. Interfering too intrusively in a student practicing various processes involved.
6. Failing to give adequate importance to creative aspects of activity (e.g., not giving an appropriate portion of available marks to that part of overall activity).
7. Overloading the student (in the module or in the wider curriculum).

6.2.2 Relating to assessment, motivation and perception

1. The assessment/evaluation of the learning process being purely extrinsic (i.e., externally determined and allowing students no or little personal ownership or say in the process.
2. Overloading the student in the module or in the wider curriculum – which often invokes the adoption of intelligent coping strategies e.g., rote memorisation or surface processing of the learning material.
3. Activities that do not involve at least simulation of the real creative process, but which are too abstracted from it (e.g., mere verbal or algebraic-numerical, 'linguistic' representations of the process).
4. Some engineers believe one has to 'produce a working model or device' before he/she is regarded as creative. This, in turn, prevents them from taking an idea further.
5. Lack of perception by the student of the relative importance and relevance of the activity.
6. Many students create new devices, approaches, etc., in a non-academic situation. For example, students in Singapore are very creative in coming up with solutions for non-academic activity, but see academic work as 'routine' and creativity as unwelcome.

7. STEM Education Brings Creativity to All

Around 85 percent of students and 91 percent of teachers see creativity as essential to a student's future career. About 83 percent of students and 94 percent of teachers feel their Gen Z students will have careers that do not exist today. The present challenging world of learning in the global economic climate is more concerned with innovation and creativity. Creativity is no longer something that is unique or distinctive. It has now become necessary and fundamental to the achievement of a person, organisation or country. **Creativity is not subject to invention only, but covers all acts and thoughts**. In effect, creativity should exist with critical thinking to drive it towards something more productive and accountable.

As the country is moving towards developed nation status, the present generation should be prepared with all forms of knowledge and skills in line with developments in technology and globalisation, in an increasingly challenging environment. We need to have a highly innovative, progressive and contributing scientific and technological civilisation for the future. To achieve this we need to have citizens who are critical, creative and capable of undertaking competent practice of science and technology in the 21st century.

The findings of a study conducted to measure the level of creativity of students in a science programme at the Faculty of Education, University of Technology, Malaysia, found that a low level of creativity had the potential to affect the process of teacher delivery of knowledge in the classroom later. Therefore, efforts should be made for science teachers to enhance creativity in order to encourage a creative learning environment in the classroom so as to **produce science students who can develop creative and entrepreneurial knowledge**. In addition, another related study was conducted to survey the practice of science students' creativity and innovation in implementing the Final Year Project (FYP). Findings showed that there is less control of creativity and innovation when implementing the FYP. It was shown that individual factors are the main factors contributing to creativity and innovation. Researchers suggested that students, teachers and the university should intensify efforts to produce students who are creative and innovative when implementing the FYP. Besides, an action research study, which included observations of students in classrooms, one using the creativity-focused curriculum and the other using the existing curriculum indicated the **enhanced science curriculum played a role in enhancing creativity of the children** in the creativity-focused group. The result of 'Thinking creatively in action and movement' test showed a significant increase in scores for children in the group focused on creativity.

Fostering creativity in education is intended to address many concerns: As a summary, this includes dealing with ambiguous problems, coping with the fast changing world and facing an uncertain future. Perhaps, the most dominant current argument for policy is the economic one. The role of creativity in the economy is being seen as crucial to assist nations for attaining higher employment, economic achievement and to cope with increased competition. It is for this reason that creativity cannot be 'ignored or suppressed through schooling' or its development be left to 'chance and mythology'. **It is predominantly for this reason that there is a call for its inclusion in education as a 'fundamental life skill'**, which needs to be developed to prepare future generations so that they can 'survive as well as thrive in the twenty-first century'. Developing children's creativity during their years in education is the start of building 'human capital' upon which, depends the 'wealth of nations'.

The creativity which has the potential to move – from the classroom to the boardroom – is the edge we need in a competitive world. Our duty as an executive is to create conditions that allow creativity to flourish – whether in the arts, sciences, commerce or industry. Creativity is as valuable in retail, education, health, government and business as in culture. The cultural sector should become the national dynamo of creative impulse that can serve all these areas. Science stimulates and excites pupils' curiosity about phenomenon and events around them and in the world. It satisfies this curiosity with knowledge. Because science links direct practical experience with ideas, it can engage learners at many levels. Scientific method is about developing and evaluating explanations through experimental evidence and modelling. This is a spur to critical and creative thought.

Recognising that creativity will be destroyed when a person is in fear, a teacher needs to be more sensitive in this regard by creating a friendlier environment for our students – more creative and able to carry out teaching and learning more interestingly and effectively. Students, who were exposed to a variety of activities that enhanced creativity and were given freedom to explore in their learning processes, have been found to be more creative.

Learning is integrating science learning with ICT. In this regard, science teachers must master skills to teach by using ICT, such as web-based learning skills, including blogs, multimedia and interactive media. Through this technology, teachers can produce scientific questions on the topic of study articles. As an alternative to improve the quality of teaching, teachers can ask questions that encourage students to think through these virtual activities. Students are given the opportunity to argue, comment, answer questions and make inquiries through a virtual forum that failed to live by the teachers through blogs, websites and so on. This virtual activity is actually capable of creating a positive mind in order to use their minds. About 93 percent of students and 73 percent of teachers view technology as the key to their career preparedness.

It is time we started teaching students to 'think for themselves' and 'ask the right questions.' Let us make sure that we do two central things. First, encourage our teachers to ask open-ended questions that stimulate thinking, and second, encourage our teachers to validate students who ask interesting questions. Then, maybe, we will begin to see some thinking in our classrooms. A robust STEM education creates critical thinkers, problem solvers, and next generation innovators. Taking into consideration that India is one of the countries that produces the highest number of scientists and engineers, the growth of STEM has picked up significantly in the last few years.

We are now at a stage where the number of STEM jobs in the world are growing at a fast pace and currently outstripping the number of STEM graduates. According to the National Science Foundation, it is predicted that 80 percent of jobs will require some form of math and science skills. Despite having top quality talent, the exam-focused education model of the past has limited these students when it comes to innovation, problem solving and creativity. This is where STEM players come in to fill the gap. The importance of the curricular range and diversity in one's college education cannot be exaggerated, even if depth forms the crux. **The ideal liberal arts science graduate is a T-shaped individual**, who combines depth with breadth or range. The vertical line of the **T** stands for depth in one's direction of specialisation. The horizontal bar stands for breadth of knowledge in a number of fields and domains. Such a graduate is much more likely to harness multiple intelligences.

8. Creativity and Society

The creative thinking process of an individual is something very complex. However, there are three phases to think creatively on how this activity happens in the mind of a person. The planned creative process involves critical and objective analysis, imaginative ideas and publishes a critical evaluation. Overall, the process involves a balance between creativity, imagination and analysis. Compared with the old approach, creative ideas result from subconscious thoughts that are usually beyond the control of a person. Therefore, the creative process requires implementation of actions and ideas. It emphasises the strength of the imagination for publication of new ideas, but we must also make it a reality of nature. Creativity is a complex mental activity very important to human life. To have the skills to think creatively, one must know the basic methods of creative thought that be truly understood, and thus one can obtain interesting results. **It is a discipline to be mastered through learning and life experiences**. One can strengthen personal and creative personality already owned. Creative teaching strategies can help students generate new ideas and explore areas in greater depth. In addition, with the appropriate technique for developing creative ideas, students can develop existing talent and always think about how best to develop further talent and ability. **Creative thinking is an important aspect in generating new knowledge that is holistic and covers all aspects of development**. Thus, nurturing creativity is important in learning to ensure quality human capital.

The educational process primarily needs to set a target on new thinking and creativity for it to have a real effect on society. India must adapt itself to be free, must have the advanced and creative way of life, and must be able to give a push in the direction of globalisation. This **will happen when we are in a position to develop into a truly creative and productive society,** and when we resist adopting ideas and copying knowledge from other countries as is being done at present. Educationist and developmental psychologist Howard Gardner persuasively **negates the theory of a single IQ** that underlines most standardised tests globally, and has pioneered the influential Theory of Multiple Intelligences. He listed seven fundamental intelligences – linguistic, logical-mathematical, musical, body-kinesthetic, spatial, inter-personal and intra-personal – to which he added three more later; naturalist, spiritual and existential. These intelligences are variously rooted in different disciplines, domains of knowledge, activities, and profession.

It is no coincidence that the top 10 countries on the World Economic Forum's Global Competitiveness Index (GCI) score highly on the 'Innovation' parameter. Efficiency has always been at the heart of any innovative undertaking and each innovation invariably leads to an increased level of productivity and economic growth. India's GCI ranking of 40 can be significantly improved with growth-path focused innovation. A 2015 report by Price Waterhouse Cooper examined India's potential growth through innovation under three scenarios: investment in human capital, in physical infrastructure and in innovation. It concluded that the **maximum gain can be derived from investment in innovation.** The Government of India has taken a few positive steps to foster a culture of innovation. **The 'Start-up-India initiative' and the 'Atal Innovation Mission' has been created along similar lines**. Startup India provides a comprehensive four week long free online learning programme and facilitates a 'fund of funds' for startups and provides incubatory support. The Atal Innovation Mission also provides incubation centres, besides encouraging children to get hands-on training in STEM concepts through Atal Tinkering Labs.

> *Unless man can make new and original adaptations to his environment as rapidly as his science can change the environment, our culture will perish.*
>
> – Carl R Rogers

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Chapter 4: Leveraging ICT for STEM Education

Our country's higher education system is basically confronted with a pentagon puzzle comprising of five issues:

1. Access and Equity (percentage of people in the eligible age group who are able to have access to higher education) and disparities with reference to region, religion, caste, gender, financial status, etc.;
2. Relevance (the relevance of education being imparted for employment or other purposes, including making them better human beings);
3. Quality (quality of education as viewed from an international perspective);
4. Governance (professional management of the vast Indian higher education system, the second largest in the world, but with no professionally trained manpower to manage it); and
5. Financing (ensuring adequate funding of higher educational institutes to ensure access to quality education).

In this chapter, we will see the role of ICT in solving this pentagon puzzle.

1. Enhancing Access, Equity and Relevance

India's higher education has witnessed a manifold increase in institutional capacity since independence. In the last 70 years, the number of universities has increased from 20 to 903, colleges from 500 to 40,000 and teachers from 15,000 to nearly 13 lakh. Consequently, the enrolment of students has increased from one lakh in 1950 to over 366 lakh in 2018. The expansion in institutional capacity in terms of the number of universities, colleges and teachers has provided greater access to post-secondary education for students. However, the gross enrolment ratio i.e., the ratio of persons enrolled in higher educational institutions to the total persons in the age group of 18 and 23 years, is still about 25.8 percent, whereas, the enrolment ratio is about 36 percent for countries in transition, 54.6 percent for developed countries with a world average of 29 percent. The situation is even worse in STEM disciplines, particularly for women in STEM where enrolment figures are very low. As per the AISHE Report 2017-18, at the undergraduate level, the highest number (36.4 percent) of students are enrolled in the Arts/ Humanities/Social Sciences courses, followed by Science (17.1 percent), Engineering and Technology (14.1 percent) and Commerce (14.1 percent).

The total number of students enrolled in Arts courses is 95.06 lakh out of which 47.2 percent are males and 52.8 percent are females. Science is the second major stream with 48.51 lakh students out of which 51.3 percent are male and 48.7 percent are female. Engineering and Technology is the third major stream with 40.19 lakh students enrolled. The share of male students enrolled in Engineering and Technology is 71.4 percent, whereas female enrolment is 28.6 percent. This stream has 17 sub-streams like electronics engineering, computer engineering, mechanical engineering, electrical engineering etc. The top five sub-streams are Mechanical Engineering with 8.8 lakh students, Computer Engineering with 8.3 lakh students, Electronics Engineering with 6.5 lakh students, Civil Engineering with 5.9 lakh students and Electrical Engineering with 4.18 lakh students enrolled. In the Information Technology/Computer Application stream, there are 7.28 lakh students enrolled. At the Post Graduate (PG) level, the maximum students are enrolled in Social Science and the Management stream comes at number two. However, in Engineering and Technology courses, 20.07 percent of the students are opting for Ph.D. after their post-graduation. It is followed by Science in which 6.9 percent of the students are opting for Ph.D. and in Medical Science 4.9 percent of the students are opting for Ph.D. In Social Science, 2.45 percent of students are opting for Ph.D. after completing post-graduation in the same field. IT and Computer Science have total number of 2,515 students with 47.8 percent male students at the Ph.D. level and 2.1 lakh students enrolled at the postgraduate level, with 51.2 percent being male students. The engineering and technology stream is divided into 19 sub-streams with a total of 38,714 students enrolled for Ph.D. and 1.92 lakh students enrolled as postgraduates. Mechanical engineering has the highest number of 5,349 students enrolled for Ph.D., with 91.1 percent being male students.

Computer engineering is the second highest, having 5,235 students with 59.84 percent male students. At the postgraduate level also, civil engineering has the highest number of 35,967 students with 70.6 percent being male students. This shows that a lot has to be done in India to increase access to higher education (the target being 30 percent by 2020). In addition to this, there are wide gender disparities, wherein access is generally lower for girls as compared to boys. It further needs to be recognised that in addition to the fact that the enrolment rates are generally lower for the females as compared to males, females belonging to the lower castes and residing in rural and backward areas, suffer more acutely in terms of having access to higher education than other females. Also, the vast difference between enrolments in urban areas as opposed to enrolments in rural areas substantiates the need for providing higher educational opportunities in rural areas, especially for girls.

Although GER is considered a vital parameter for the Indian higher education system, a close scrutiny will reveal that the problem is deeper. If one considers the Eligible Enrolment Ratio (EER), i.e., the ratio of number of students enrolled in higher education to the number of persons who have passed Class XII in the age group of 18-23, a different scenario emerges. The EER for India is about 55-60 percent, almost matching developed countries. The more astonishing fact is that the EER is almost the same, cutting across caste, religion, region and gender disparities. One would agree that we don't wish to target 100 percent EER as we need skilled manpower in many areas for which higher education may not be an essential requirement. On the other hand, the

Government of India has taken many effective steps to increase school enrolment, including the Right to Education Bill and Sarva Siksha Abhiyaan. This will lead to more number of school pass outs in times to come, and hence, even if the EER is sustained at the same level of 55-60 percent, the number of enrolments in institutes of higher education will increase. Therefore, there is a **need to shift the focus from 'creating expansion' to 'accommodating expansion'.** This capacity enhancement of higher education space needs a **multi-pronged** approach.

Firstly, the government can create additional infrastructure by investing heavily for this purpose. New schemes like Higher Education Funding Agency (HEFA) and Revitalising Infrastructure and System in Education (RISE) in the Union Budget of 2018 are positive steps in this direction. However, the desired funding is not forthcoming in the required proportions and we are still far off the target of investing six percent of GDP in education.

The **second** alternative could be to involve private players in the field through the route of private deemed universities, private state universities and private colleges. This has been resorted to, and today, about 60 percent of higher education institutions are in the private sector. There is, however, a lurking fear of their adverse effect on the quality of education if not regulated properly. The issue of 44 deemed universities that were branded unfit by the P.N. Tandon Committee and the actual closure of about 104 state private universities, created by a single Act in the state of Chhattisgarh by the Supreme Court of India are classic examples of deterioration in quality by some of the private universities which mainly run as commercial enterprises purely with a profit motive. This is at total variance with establishments of the past, when education was considered a philanthropic activity and premier institutions like the Aligarh Muslim University, Birla Institute of Technology and Science-Pilani (BITS-Pilani), Birla Institute of Technology and Science-Ranchi (BITS-Ranchi), Tata Institute of Social Sciences (TISS), Tata Institute of Fundamental Research (TIFR), The Energy and Resources Institute(TERI) etc. were established by private houses, not for profit making, but for serving the people of the nation.

Thirdly, we can consider the careful amalgamation of conventional and distance education, while ensuring that quality is not compromised to increase quantity. The UGC's recent regulations for open and distance learning, and online education are a welcome step in this direction as they are quite rational to curb non-quality distance education institutions and promote quality distance education without compromising on quality.

Fourthly, for providing access to quality higher education to such a mammoth young population located across the country, an innovative time bound approach would be required. With Information, Communication and Technology (ICT) making inroads in the education sector worldwide, the government launched the ambitious National Mission on ICT (NMEICT) in 2009, for employing technology to provide connectivity, along with a provision for multiple access devices to institutions and learners, and for content generation.

A hallmark of vibrant educational institutions and disciplines is their curricular content, which should evolve continuously.

It is felt that education being imparted in many of our higher education institutions is largely irrelevant. The curriculum is outdated and syllabus updation is at the whim and fancy of teachers who resist it as they have to keep themselves updated following any change in syllabus. It is surprising that in spite of following a project-based learning methodology in many universities, **most of our pass outs are unemployable** (As per a Confederation of Indian Industry Report, our students have little industry or hands-on experience, and consequently, about 78 percent of professional graduates we produce are unemployable) and industries, companies and institutions have to arrange for special induction training to make students employable. The relevance of education being imparted, both in terms of content and methodology, is being widely debated. We need to take urgent steps to contain the situation, especially in STEM areas, and make education relevant for our students in the future. With the advent of technology, knowledge enhancement is easier and faster. Students should be prepared to keep themselves updated in their fields by self-learning through massive open online courses (MOOCs) and other online courses available on platforms like Swayam, Edx, Coursera, Udacity, and Khan Academy etc.

Teachers must start using the Open Education Resource available on the Internet to teach students in a 'Flip Classroom Model' whereby, students receive the text and see videos on the NET recommended by teachers, and come to the class for a discussion to improve their understanding and clear their doubts. This will allow students to grasp the application of the concept, rather than just memorise it by rote learning.

2. Introduction of Computational Thinking in Curriculum

To make our education relevant for producing employable graduates, our curriculum has to be reoriented and refocussed based on what is happening across the world. There has to be a major component of '**Computational Thinking**' right from the school level till the higher education level. A tentative formulation for introducing computational thinking in the curriculum, right from school till higher education level is given below:

2.1 At Elementary School

Even young children (Class I to V corresponding to ages 6 to 10) can be introduced to computational thinking. The specific programmes at this stage need to be designed keeping the environment of children in mind. A high-quality computing education equips pupils to use computational thinking and creativity to understand and change the world. The United Kingdom (UK) took the lead several years ago to introduce appreciation of computational thinking and introduced computer programming at the school stage itself. **This is worth a trial in India, at least in a phased manner.** The national curriculum for computing in the UK aims to ensure that all pupils:

1. can understand and apply the fundamental principles and concepts of computer science, including abstraction, logic, algorithms and data representation;
2. can analyse problems in computational terms and have repeated practical experience of writing computer

programmes in order to solve such problems;

3. can evaluate and apply information technology, including new or unfamiliar technologies, analytically to solve problems;
4. are responsible, competent, confident and creative users of information and communication technology.

Students at the elementary level should be taught to:

1. understand what algorithms are; how they are implemented as programmes on digital devices; and how programmes are executed by following precise and unambiguous instructions;
2. creates and debug simple programmes;
3. use logical reasoning to predict the behaviour of simple programmes;
4. use technology purposefully to create, organise, store, manipulate and retrieve digital content;
5. recognise common uses of information technology beyond school;
6. use technology safely and respectfully, keeping personal information private; identify where to go for help and support when they have concerns about content or contact on the Internet or other online technologies.

2.2 At Middle School

At the Middle School level (Classes 6 to 8 corresponding to ages 11 to 13), students should be taught to:

1. design, write and debug programmes that accomplish specific goals, including controlling or simulating physical systems; solve problems by decomposing them into smaller parts;
2. use sequence, selection and repetition in programmes; work with variables and various forms of input and output;
3. use logical reasoning to explain how some simple algorithms work and to detect and correct errors in algorithms and programmes;
4. understand computer networks, including the Internet; how they can provide multiple services, such as the World Wide Web; and the opportunities they offer for communication and collaboration;
5. use 'search technologies' effectively, appreciate how results are selected and ranked and be discerning in evaluating digital content;
6. select, use and combine a variety of software (including Internet services) on a range of digital devices to design and create a range of programmes, systems and content that accomplish given goals, including collecting, analysing, evaluating and presenting data and information;
7. use technology safely, respectfully and responsibly; recognise acceptable/ unacceptable behaviour; identify a range of ways to report concerns about content and contact.

2.3 At Secondary School (Class IX-X)

At this level, the student should be taught to:

1. design, use and evaluate computational abstractions that model the state and behaviour of real-world problems and physical systems;
2. understand several key algorithms that reflect computational thinking (for example, ones for sorting and searching); use logical reasoning to compare the utility of alternative algorithms for the same problem;
3. use two or more programming languages, at least one of which is textual, to solve a variety of computational problems; make appropriate use of data structures (for example, lists, tables or arrays); design and develop modular programmes that use procedures or functions;
4. understand simple Boolean logic (for example, AND, OR and NOT) and some of its uses in circuits and programming; understand how numbers can be represented in binary, and be able to carry out simple operations on binary numbers (for example, binary addition, and conversion between binary and decimal);
5. understand the hardware and software components that make up computer systems, and how they communicate with one another and with other systems;
6. understand how instructions are stored and executed within a computer system; understand how data of various types (including text, sounds and pictures) can be represented and manipulated digitally, in the form of binary digits;
7. undertake creative projects that involve selecting, using, and combining multiple applications, preferably across a range of devices, to achieve challenging goals, including collecting and analysing data and meeting the needs of known users;
8. create, re-use, revise and re-purpose digital artifacts for a given audience, with attention to trustworthiness, design and usability;
9. understand a range of ways to use technology safely, respectfully, responsibly and securely, including protecting their online identity and privacy; recognise inappropriate content, contact and conduct and know how to report concerns.

2.4 At Senior Secondary School (Class XI-XII)

At this level, all students must have the opportunity to study aspects of information technology and computer science in sufficient depth to allow them to progress to higher levels of study, or to a professional career. They should be taught to:

1. develop their capability, creativity and knowledge in computer science, digital media and information technology;
2. develop and apply their analytic ability, problem-solving, design, and computational thinking skills;
3. understand how changes in technology affect safety, including new ways to protect their online privacy and identity and how to identify and report a range of concerns.

2.5 At University Level

This was a news item that appeared recently. **Asia's top university makes computational thinking compulsory.** To many, the idea of pushing through significant changes at Asia's most highly ranked university would be nothing short of madness. But even though the National University of Singapore has topped Times Higher Education's Asia University Rankings for three years continuously, the new leader of the city state's flagship institution could not be calmer about rocking the boat. Tan Eng Chye, who became NUS President in January after more than a decade as Provost, the institution's number two position, said that he was not afraid to rethink the university's entire approach to teaching in order to 'future-proof' his 28,000 students for a world increasingly shaped by digital technology and automation.

'Things are moving very fast in the external environment and we cannot afford to keep still,' said Professor Tan. 'The fourth industrial revolution is crucial. My colleagues know this and they understand that we must change with the times because of it.

Professor Tan, who completed his undergraduate degree at NUS and has been on the faculty since 1985, said that his predecessor, Tan Chorh Chuan, had 'set very strong foundations for the university', pushing it up to 22nd in the World University Rankings, up 18 places in just five years. But Professor Tan said that he 'will have to take it much higher', acknowledging that 'certainly, there's pressure on me to continue to do better'.

'Much to the angst of some students, I have made statistics as well as computational thinking or programming compulsory for everyone, regardless of what course they do,' Professor Tan said.

In accordance with Singapore's goal of creating a sustainable knowledge economy, Professor Tan's new mandatory requirement means that even art and music students will be required to cover some level of computational thinking – for instance, understanding algorithms in everyday life.

'Some students don't react well, but it's good for them to be sensitized,' he said. 'They may not have to do programming [when they graduate], but I think in this new world where technology is really disrupting our everyday life, it is good for a university student to have some understanding.'

Moving away from the reading and regurgitation approach to learning traditionally loved within Asian education systems, Professor Tan also wants to put more focus on 'experiential training'.

It is these skills that will ensure Singapore does not fall behind its Asian competitors in the future employment landscape. 'No question, China will be changing very quickly, and if we want to stay ahead, we need to move just as quickly, if not faster,' Professor Tan explained.

Above all, preparations made for future graduate skills will benefit all Singaporeans in terms of the economy, Professor Tan said. 'Students today will graduate at 22 and most likely work until they are 70,' he said. 'We cannot train them up in just one trade any more'.

3. Computational Thinking

Computational thinking is a set of cognitive skills and techniques that can be used to support problem solving across situations and disciplines. More specifically, Computational Thinking entails:

- **Decomposition** – breaking a (big, complicated, complex) problem into smaller parts or steps;
- **Pattern Recognition** – finding and identifying patterns and trends in data;
- **Abstraction** – identifying general principles that generate these patterns;
- **Algorithm Design** – developing instructions for solving the problem.

Step by step, part by part, the solutions to small problems can be brought together and help shed light on and provide a solution to big and complex problems. Computational Thinking is useful as a problem solving methodology, but beyond that, training in computational thinking can also help cultivate positive learning attitudes and values, such as tinkering and experimenting with solutions, debugging through finding and fixing errors, perseverance in working with difficult and open-ended problems, and confidence in dealing with ambiguity and complexity. It is extremely unfortunate that educators, policymakers or students don't want to learn new concepts that can help future-proof their careers. They would rather agitate for concessions and guaranteed employment. But, as has been so well stated in the video by CGP Grey about 'Humans need not apply'; **economics always wins, and humans without the right skills, will have a very tough time in the future.**

3.1 Computational Thinking for Lifelong Learners: MOOCs

Computational thinking is projected to be the 21st century skill necessary for all age groups because of its applicability to different fields. Hence, **learning to think computationally should not be limited to formal studies, but should be accessible to learners of all age groups** just like any other subject such as mathematics, humanities or sciences. Wing advocated for computational thinking courses, which are catered to thinking abstractly and might be helpful in developing interest in the field of complex problem solving. **Computational thinking is critical for solving problems and using data effectively in modern society.** It is really a way to solve problems by specifying step-by-step solutions, collecting, representing, and analysing data to support drawing conclusions or making decisions, and using a variety of techniques to improve the efficiency of problem solutions. Lifelong learners may pursue whatever courses (MOOCs or otherwise) that they can find access to, courses that help them learn key computational thinking topics and develop skills in those areas. Refs. 12-17 are some links to a few courses that a lifelong learner can explore.

4. ICT as a Solution to the Pentagon Puzzle

Online education in India is a mixed structure of both dedicated online and offline contributors. The Customer-to-Customer (C2C) business models of online education have provided a very sound platform, where the entire system connects to prospective teachers and students. On the other hand, the

Business-to-Business (B2B) model is much more prevalent in higher education, where corresponding institutions offer degree/ diploma courses to students through their own platforms on their terms and conditions, or it may be done through third party aggregator corporate tie-ups who assist for the development of industry certified content, that provides overall acceptance of online education amongst target users. Efficient Internet connectivity and a massive shift towards digital payments have significantly played an important role for the growth of online education in India. The online channel of education is increasingly gaining acceptance amongst the student community in India because of the aforementioned reasons. Students, therefore, get connected to each other via Internet and they interact with each other by sharing their notes, innovative ideas, and engage in constructive dialogue on a common platform. The online education ecosystem will observe stronger collaborations between platform providers and corporates in the near future.

The key players of the online education structure could get associated and connected to the industry which will help them develop content that is relevant for the current job-market.

Online certifications and re-skilling oneself can also lead to enhanced employment opportunities which are being offered only to certified students. This could be facilitated more by suitable corporate partnerships in relevant industries. Industry collaborations provide a real time opportunity to students through the following:

4.1 Internship Opportunities

This platform could offer better internship opportunities to high-performing students that will give them insight of real working environments. The structure and the working of these internships could be designed with the help of appropriate industry partnerships.

4.2 Short-term Assignments and Live Projects

Industry experts/professionals can design some live short-term projects for associated students with respect to their requirements. The students can also be assigned with short-term assignments that will enhance the overall learning process and also provide the platform with required practical experience.

4.3 Growth drivers of Online Education System in India

1. **Online education provides a low cost alternative:** Lower infrastructure costs and a larger student base helps leverage on economies of scale, and hence, reduces prices via the online channel. Online skill enhancement courses are nearly 53 percent cheaper than other traditional alternatives [4].
2. **Online channel provides quality education to potential students:** Open courses and distance learning enrolments in India are expected to rise to around 10 million in 2021, growing at a CAGR of around 10 percent. Areas where availability of quality offline education is low, witness higher adoption of non-traditional education methods.

3. **Growing job seeking population drives the demand for industry relevant training.**
4. About 280 million job-seekers are expected to enter the job market by 2050 [9]
5. The unemployment rate in India was at a five year high of around five per cent in 2016 [10].
6. The annual growth rate in terms of availability of jobs is at around two per cent per annum.

4.4 Government Initiatives to Drive Adoption of Online Education

1. Government initiatives such as SWAYAM, E-Basta, Rashtriya Madhyamik Shiksha Abhiyan (RMSA), Skill India, Start up India and Digital India will create the infrastructure needed by students to study online.
2. **Internet penetration witnessing exponential growth across India**
3. India has seen an enormous growth in the rate of Internet users across the country, with around 409 million users today. [11]. With the ease of accessibility and affordability of smart phones, users are growing exponentially day-by-day, which brings everything just a touch away.
4. **A large fraction of the Indian population is young, thus enlarging the target population for online education**
5. The youth of the country is nearly 46 percent which lies in the age group of approximately 15-35 years [12]. The acceptability of online education is the highest in this age segment as they are highly inspired and may be low earners as well, so they find the option of online education more suitable as compared to the traditional system of education.

4.5 Factors for Adopting Online Education

1. **Category of students:** More students with a science background opt for online education as compared to the ones studying humanities or commerce. Working professionals – the ones who had to drop their studies for several reasons and are now in the working sector, get an opportunity to continue with their studies or take up some advanced professional courses which will help them excel in their working domain.
2. **Quality of content:** A major reason for students adopting online education is the abundance of online content available which makes it easier for them to gain in-depth knowledge about content. The graphical nature of content makes it more attractive and interactive for students to understand topics.
3. **Better concentration at home:** It is observed that there are numerous factors that act as distractions for students once they are out of their homes. It may be friends, environment, or other reasons. Whereas on the other side, if we see the situation where students are at home and away from distractions, they can focus more on core studies. They are equipped

with content and syllabus and can invest quality time in studies.

4. **Online Tutors:** With the emergence of online education, several tutors have also registered themselves for delivering online lectures. Students can take up the option of online tutors of their own choice and get connected for clearing doubts at a convenient time.
5. **Variety of courses:** The online education system provides many courses which can be taken up as per choice and convenience by paying a nominal fee for the same. In the traditional education system, students do not have any option as to choice of curriculum, but here, they have full authority to choose whatever they wish to study. Student are not bound by constraints of marks and streams in which they have been fixed for three to four years of higher education.
6. **Choice of selecting a variety of subjects:** Online education also allows flexibility to design the curriculum for students as per their choice. The student can read the subjects in any combination which is not at all possible in the traditional education system. A science student good at automobiles can also read psychology or geography which may be an area of interest or a commerce student may read programming as a second choice of subject. This flexibility of designing one's own choice of subjects is only possible through online education.
7. **Mode of fee payment:** The fee for the course adopted may be paid through several ways, including full payment online at the time of purchasing the course or through installment basis during the duration of the course. The mode of payment includes both digital payments and cash payments, whichever is suitable to the person.
8. **Examinations:** The examination system has been entirely changed over the years. With the emergence of a huge job market, a majority of the segments are conducting objective-based examinations which can be better conducted using computer technology which saves a lot of time and cost.
9. **On Demand Examination System (ODES):** Students have a very high flexibility to give their exams as per their choice i.e., they can design their examination schedule as per their convenience. In traditional examination structures, students don't have any choice over the schedule, they have to take up the exam as per the slot pre-decided and given to them.
10. **Credit based evaluation:** The evaluation system should be transformed completely to the credit-based system, rather than the currently available marks-based system. The student is liable to score a minimum number of credits for the completion of a particular course, which can be done in any time duration.
11. **Regional Language-specific content:** As we know, India is a multi-linguistic country where a majority of the population is residing in rural areas and this population is very close to

their regional language. The content can be made available to students in their specific language through the appropriate use of Internet, through the various kinds of software available which convert English content into the desired language. This will bring education closer to the people, specifically in rural areas.

12. **Technical Certifications:** The online re-skilling and certifications market is comparatively very high as compared to other categories of online education in India. The online channel is preferred due to the convenience factor and shorter duration of courses. The category is expected to continue growing at a very high rate as it is driven by the need of professionals to continuously learn evolving technologies and the demand from new entrants to the workforce trying to find a space.

4.6 Outcome of the Technology-enabled Learning Initiatives

As mentioned in the beginning, technology-enabled learning will help us to solve the pentagon puzzle of higher education. The issues of relevance and quality would be addressed through quality e-content made available to students in the form of e-pathshala (OER and Flipped Classroom model). The DTH videos being telecast through SWAYAMPRABHA would address the issue of equity by reaching out to students and learners located in the remotest corners of the country. Technology-enabled learning initiatives would go a long way in cutting down the costs of building infrastructure in the form of brick and mortar class rooms, thereby addressing the problem of financing higher education. Online content will also address the problem of management of faculty shortage in universities and colleges by providing students with the best quality faculty from across the country.

Summing up, OER, MOOCs and DTH would provide students and teachers with different approaches to learning and innovation in teaching and optimally use the resources and time on hand. The project would also help students and teachers to update their knowledge and skills, especially for those located in rural/backward/remote areas and would successfully bridge the digital divide, and help the nation move towards an information-rich society.

5. Online Learning Helps in Best Utilisation of Time and Improves Motivation

Smart phones and laptops are seen in everyone's hand and that too, with Internet connectivity. It is very easy for people to spend hours and hours browsing the Internet or being involved with social media, or just surfing the web, If this engagement can be substituted by online learning, it can provide a better and more productive way of utilising one's free time. With a society of more productive citizens who excel in time management, there is going to be greater overall improvement in our organisational skills and thirst for knowledge.

5.1 Consequences/Disadvantages of Online Programmes

1. **Lack of human touch:** The major drawback of the online concept of

universities is expected to be lack of human touch, which will completely eliminate the socialising behaviour of students among themselves and their faculties. Learning is a social process which is best accepted by the to and fro flow of questions, doubts and responses in specially designed sessions that help us all put everything together.

2. Assessment Effectiveness: The authenticity of students while doing their assignments may not be very true, and hence, assignments presented or the tests taken up may not be highly effective. A student may be genuine in one's own sense, but the system may not be completely capable of examining and judging the student's performance fairly.

3. Credibility: Online courses and certifications have grown enormously in numbers across the digital space which gives birth to the need of assessing the credibility of an online degree, or course. Students should always check the credibility of online courses before getting associated with them.

4. Employability in India: When it comes to employability in a developing country like India, it is very difficult to sustain with online courses or degrees as there has to be an accreditation through several boards or agencies without which the degree does not have any value in the market.

5. Technical problems related to ICT: Though ICT has given birth to a new era of digital world, there are certain technical problems which are associated with the massive application of ICT in the sector of education. Some of the common mistakes in introducing ICTs into teaching are installation of technologies without reviewing the needs of students and current availability of content. Another major issue is of imposing technological systems without physical and direct involvement of students and teachers. The last and most important aspect is of developing low quality content which may be poorly designed and may not include correct and relevant information. Although ICT-related education offers a whole lot of benefits, there are some risks which have to be mitigated with the use of proper mechanisms.

6. Low retention rates of students: The absence of the classroom factor makes it difficult to maintain the interest of students, especially during long-term courses, which ultimately results in lower retention of originally mass enrolments. It also leads to lower motivational levels of students as there is no social interaction between the student and the instructor. This may lead to low problem solving rates on discussion forums etc. Due to this, a large number of students may go off-track, and hence, this leads to low retention rates for the next level of courses.

7. High installation and maintenance cost: A major issue related to implementation of ICT is the high cost of acquiring, installing, operating and maintaining components or devices

involved with it. ICT is proving to be potentially of great importance and a big asset but it is still not easy for integrating components of ICTs. The cost of purchasing and installation of these components are comparatively high in developing countries. Thereafter, the operational and maintenance cost of ICT-enabled devices for the purposes of education turns out to be very high as compared to developed countries.

Apparently, online and distance education models in STEM higher education may have their own limitations mainly due to lack of hands-on/eye-contact type of training. Nevertheless, these modes shall have great supporting and supplementary roles in STEM in terms of vast knowledge/information discrimination, much wider penetration of the expert's ideas and general awareness among masses. This, in fact, is critical to a country like ours with a unique and highly diverse demography. Having discussed in detail the above innovative distance modes of learning, new mechanisms should be devised and integrated judiciously into STEM education to realise its full impact.

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Chapter 5: STEM Education in USA and China – A Case Study

The fields of Science, Technology, Engineering, and Mathematics (STEM) are collectively known as core technological foundations of modern society. The term STEM is a modified version of SMET (Science, Mathematics, Engineering and Technology), which was used by academicians from Winona State University in Minnesota while preparing a curriculum for these subjects in the year 2000. It is believed STEM was considered a better sounding option. The strength and strategies of the STEM workforce of a nation are taken as indicators of its ability for sustainable development and growth. As a case study, it is worthwhile and interesting to trace the development of STEM in the USA and its present status. Equally interesting is the fact that China also has practically emerged as the most dominant player in STEM and this is most relevant for India. So, we also attempt to study the progress of STEM in China. Finally, for completeness, a brief overview of some other countries is given.

1. STEM in the United States of America

On 31 January 2006, in his State of the Union Address, then President, George W. Bush, declared the American Competitiveness Initiative. President Bush suggested the initiative to address deficits in federal government support for educational development and growth for all academic levels in STEM fields. The initiative demanded a significant increase in federal funding for advance in research and development programmes (including doubling of federal funding support through Department of Education for advanced research in the physical sciences) and an increase in American higher education graduates within STEM disciplines. The United States National Academies, in 2006, expressed alarm about the declining state of STEM education in the country. Its Committee on Science, Public Policy and Engineering came up with 10 action points which could help in the advancement of STEM education in the United States to retain its dominating place in the 21st century. The top three recommendations were:

- To improve K-12 science and mathematics education in order to increase America's talent pool;
- To provide additional skill-based training to teachers in science, technology and math; and
- To increase the number of students graduating with a STEM degree.

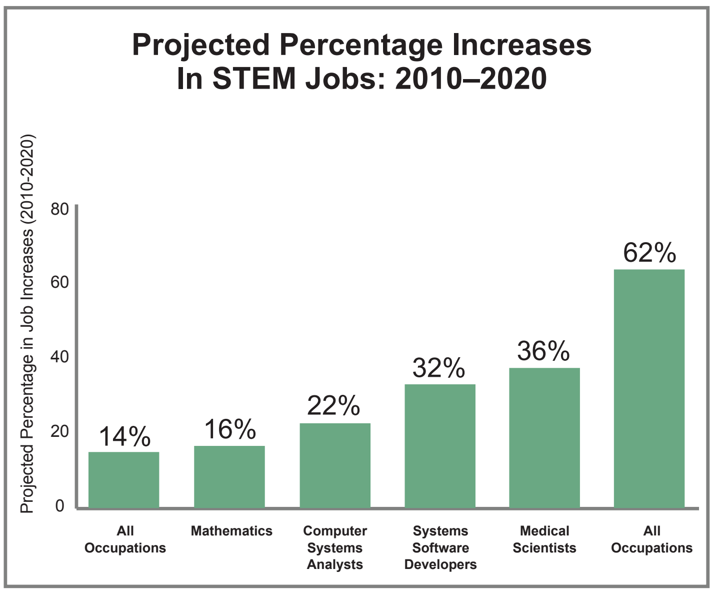
The National Science Foundation (NSF) has offered several programmes in STEM education, which include a few for K-12 students e.g., the ITEST Programme that supports The Global Challenge Award ITEST Programme. There are many organisations in the United States which follow National Science Foundation guidelines on what kind of

STEM field is constituted. A broader definition of STEM subjects, including subjects in the fields of computer and information technology science, engineering, mathematical sciences, chemistry, geosciences, life sciences, physics, astronomy, and social sciences (anthropology, economics, psychology and sociology), has been used by the NSF.

The NSF is the only American federal agency with a mission to include support for all areas of fundamental science and engineering, except medical sciences. Interdisciplinary programme fields include grants, scholarships and fellowships in fields such as biological sciences, education and human resources, computer and information science and engineering, geosciences, environmental research and education, cyber infrastructure, international science and engineering, mathematical and physical sciences, social, behavioral and economic sciences and polar programmes.

Science education has remained a top priority for federal as well as state governments since decades for economic reasons. Federal support for basic research in natural sciences is controlled by the United States Congress which takes action based upon public interest and special interest groups such as industry and business. The United States has seen a steady decline of interest among students in the natural sciences in general and STEM in particular in the last few decades, since strenuous efforts are required for relatively longer periods. Female enrollment in the STEM programme has been declining even more. This has resulted in sustained efforts by various agencies, including the Department of Education and the National Science Foundation to promote STEM programmes by granting free-ships/scholarships and creating STEM infrastructure, and specifically training teachers to teach STEM courses.

It has been projected that between 2010 and 2020, there will be a great surge in STEM related jobs both in industry and business. Bio-medical engineering jobs are projected to grow by 62 percent, medical scientists by 36 percent, system software developers by 32 percent, computer system analysts by 22 percent, mathematics by 16 percent and all occupations, including STEM, by 14 percent.



The document titled, 'Science, Technology, Engineering and Math: Education for Global Leadership' available on the website of the US Department of Education states that, 'All young people should be prepared to think deeply and to think well so that they have the chance to be the educators, innovators, leaders and researchers who can find out solutions for the most difficult challenges our country and the world are facing today or may face tomorrow. But, at present, our young generation doesn't have access to good quality STEM learning prospects and very less students take these disciplines as springboards for their careers'. The Committee on STEM Education (CoSTEM), during the Obama Administration, consisted of 13 agencies comprising of all mission-science agencies and the Department of Education which facilitated a unified national policy with fresh and repurposed funds in order to improve the effect of federal investments in five areas:

1. To improve STEM instruction from pre-school through 12th grade;
2. To increase and sustain public and youth engagement with STEM;
3. To improve the STEM experience for undergraduate students;
4. To encourage better serving groups which are historically underrepresented in STEM fields; and
5. To design graduate education for the future STEM workforce.

A federal five year strategic plan for STEM education was notified in May 2013 by National Science and Technology Council with the approval of the United States Congress. The opening para of the Executive Summary of the Plan reads as under:

> *Advances in science, technology, engineering and mathematics (STEM) have long been central to our Nation's ability to manufacture better and smarter products, improve health care, develop cleaner and more efficient domestic energy sources, preserve the environment, safeguard national security, and grow the economy. For the United States to maintain its pre-eminent position in the world, it will be essential that the Nation continues to lead in STEM, but evidence indicates that current educational pathways are not leading to a sufficiently large and well-trained STEM workforce to achieve this goal. Nor is the U.S. education system cultivating a culture of STEM necessary for a STEM-literate public. Thus, it is essential that the United States enhance U.S. students' engagement in STEM disciplines and inspire and equip many more students to excel in STEM.*

The STEM Strategic Plan gave a determined national objective to run federal investment in five priority STEM education fields which are:

1. Improving STEM Instruction: To prepare 100,000 excellent new K-12 STEM teachers by 2020, and to support the present STEM teacher workforce;
2. Increasing and Sustaining Public Engagement and Youth in STEM: Each year to support 50 percent US youth who have genuine STEM experience before completion of high school;
3. Enhancing the STEM experience of undergraduates: To graduate 10 lakh more students with degrees in STEM in the next 10 years;
4. To Better Serve Groups previously under-represented in STEM fields: To increase the number of students from groups who have been under-represented in STEM fields earlier within the next 10 years and to improve female participation in areas of STEM where they are drastically under-represented; and

5. Designing graduate education for tomorrow's STEM workforce: To provide graduate-trained STEM professionals with basic and applied research expertise, options to acquire specialised skills in areas of national importance, mission-critical workforce needs for CoSTEM agencies and ancillary skills needed for success in a broad range of careers.

The United States Department of Education had in 2015, along with the American Institutes for Research (AIR), organised many 1.5-day workshops where invited specialists and leaders in STEM teaching and learning shared their views and suggestions for an enhanced future of STEM. Approximately 30 professionals who represented a vast amount of knowledge and skill became a part of this project. These experts were selected on the basis of their work in the fields of grabbing sciences research, equity and access, assessment and measurement, culturally relevant teaching and learning; pre-school through 12th-grade education technology, post-school higher education and informal STEM learning, and community networks of learning. The report titled 'STEM 2026 – A Vision for Innovation in STEM Education', put forth recommendations, key observations and considerations by the participants of the workshop. Vision 'STEM 2026' lays importance on STEM education as under:

> *The complexities of today's world require all people to be equipped with a new set of core knowledge and skills to solve difficult problems, gather and evaluate evidence, and make sense of information they receive from varied print and, increasingly, digital media. The learning and doing of STEM helps develop these skills and prepare students for a workforce where success results not just from what one knows, but what one is able to do with that knowledge. Thus, a strong STEM education is becoming increasingly recognised as a key driver of opportunity, and data show the need for STEM knowledge and skills to grow and continue into the future. Those graduates who have practical and relevant STEM precepts embedded into their educational experiences will be in high demand in all job sectors. It is estimated that in the next five years, major American companies will need to add nearly 1.6 million STEM-skilled employees (Business Roundtable and Change the Equation, 2014). Labor market data also show that the set of core cognitive knowledge, skills, and abilities that are associated with a STEM education are now in demand not only in traditional STEM occupations, but in nearly all job sectors and types of positions (Carnevale, Smith, & Melton, 2011; Rothwell, 2013).*

As per the STEM 2026 report there are persistent inequities in access, participation and success in STEM subjects that exist along racial, socio-economic, gender, and geographic lines, as well as among students with disabilities. STEM education disparities threaten a nation's ability to close education and poverty gaps, meet the demands of a technology-driven economy, ensure national security and maintain pre-eminence in scientific research and technological innovation. The six components of STEM

2026 which are interconnected are described in this report in detail. Further, the challenges and opportunities for innovation in order to bring changes in these components to make them practical were deliberated:

1. Engaged and networked communities of practice.
2. Accessible learning activities that invite intentional play and risk.
3. Educational experiences, including inter-disciplinary approaches for solving 'grand challenges.'
4. Flexible as well as inclusive learning spaces.
5. Innovative and accessible measures of learning.
6. Cultural and societal images and environments that promote opportunity and diversity in STEM.

President Donald Trump signed a 'Presidential Memorandum on Creating Pathways to Jobs by Increasing Access to Jobs by Increasing Access to High-Quality Science, Technology, Engineering, and Mathematics (STEM) Education' on 25.09.2017 affirming his administration's 'strong commitment for enabling and encouraging students across the country to engage in high quality STEM education, including computer science.' Section 1 of the Presidential Memorandum reads as under:

> *A key priority of my Administration is to better equip America's young people with the relevant knowledge and skills that will enable them to secure high paying, stable jobs throughout their careers. With the growing role of technology in driving the American economy, many jobs increasingly require skills in science, technology, engineering, and mathematics (STEM) – including, in particular, Computer Science. These skills open the door to jobs, strengthening the backbone of American ingenuity, driving solutions to complex problems across industries, and improving lives around the world. As part of my Administration's commitment for supporting American workers and increasing economic growth and prosperity, it is critical that we educate and train our future workforce to compete and excel in lucrative and important STEM fields.*

The memorandum further states: 'Shortages in high-quality STEM teachers at all levels, particularly in computer science, often drive these problems. The Department of Education, therefore, should prioritise helping districts recruit and train teachers capable of providing students with a rigorous education in STEM fields, focusing in particular on computer science. This will help equip students with skills needed to obtain certifications and advanced degrees that ultimately lead to jobs in STEM fields.' The memorandum further lays emphasis on 'establishing promotion of high-quality STEM education, with a particular focus on computer science, as a Department of Education priority' and 'establishing a goal of devoting at least $200 million in grant funds per year to the promotion of high quality STEM education, including computer science in particular'.

The US Department of Education has issued various policy papers on diverse subjects related to the promotion of STEM education, including 'Encouraging Girls to take STEM Courses in US'; 'Assisting Students Struggling with Mathematics'; 'Higher Education and Secondary Schools Coming Together'; 'Increasing-the-Success-of-Minority-Students-in-Science-and-Technology-2006'; 'Teaching Math to Young Children' and many more since students who lack interest in science subjects at the school level fail to enroll in STEM programmes in higher education. The focus on promotion of STEM courses is laid at the school level by state governments and local school districts, which is financially supported by the federal government. Universities have been supporting schools and community colleges to promote STEM courses among students for which universities have also opened their doors to school students to experience their learning environment.

NASA is promoting STEM education under the title, 'NASA Education' which leverages the agency's unique mission of research and discovery as a powerful context for student-oriented learning. Since the date of its creation in 1958, NASA is committed to bring advancements in STEM in many ways such as concepts, careers, and awareness for learners, educators and institutions. NASA helps learners by providing content through activities which further bridge critical gaps and help in gaining exposure and pursuing STEM careers. By giving access to the best technical and research facilities, technical experts and mission data, NASA desires to have and retain students of diverse background in STEM career areas and wants to advance STEM research by upgrading the domestic capacity of organisations.

The NASA Education Implementation Plan (NEIP) 2015-17, provided an understanding of the role of NASA for promoting the nation's STEM education and work force. The document outlined the roles and responsibilities of 'NASA Education' in approaching and achieving its administration's strategic goals in STEM education. The purposes of the 2015-17 NASA Education Implementation Plan were:

1. An alignment between NASA Education and the nation's priorities and the 2014 NASA Strategic Plan;
2. The framework for definite and quantifiable outcomes for guiding and monitoring performance in the educational portfolio only;
3. The responsibilities, roles and management of the Associate Administrator for Education, the Office of Education, Mission Directorate Leads, and Education Offices;
4. The key agency stakeholders who are responsible for strategic coordination and requirements development; and
5. The monitoring and control structure to determine the outcomes of NASA's education portfolio within the agency.

The Association of American Universities, founded in 1900, comprising of 62 renowned institutions which continually advance society with the help of education, research and discovery, has also come up with number of policy documents on STEM education at the undergraduate level, including 'Essential Questions and Data Sources for Continuous Improvement of Undergraduate STEM Teaching and Learning' and 'Framework for Systemic Change in Undergraduate

STEM Teaching and Learning.' US Federal Government has enacted a number of laws for promoting STEM education, including, 'The America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act of 2007'; 'STEM Jobs Act of 2015'; 'STEM Education Act of 2015'. STEM education is definitely a top priority of all stakeholders in the US, as hundreds of agencies apart from universities and schools have contributed for promotion of STEM education by providing funds and resources.

STEM Enrolments in USA

1. From the year 2000 to 2012, approximately one-third of the bachelor's degrees conferred by US colleges and universities every year were in science & engineering fields which gradually rose from 398,602 in 2000 to 589,330 in 2012.
2. The number of S&E bachelors' degrees conferred to women increased from 200,952 in 2000 to 297,539 in 2012. The number of S&E bachelor's degrees awarded to men in this period rose from 197,650 to 291,791.
3. Between 2000 and 2012, the annual number of S&E bachelors' degrees rose by 48 percent in both women and men.

2. STEM in China

In China, science means mathematics, basic natural science and interdisciplinary subjects. Science, which explores the natural law, further drives science and technology (S&T) and economic development. Science is the base which helps in the advancement of human civilisation. Talents can be cultivated and research spirit can be nurtured only through science education, especially in the case of higher education sectors. Hence, scientific literacy becomes indispensable for university students as it can further lead to economic prosperity, social upliftment, national security, and science and technology development of the nation. This scientific literacy helps in generating innovation which further supports the nation in standing tall in a competitive environment. The higher education system is dependent on such innovation and even the nation too. Hence, science education is a strategic priority in China. In 1949, with the foundation of the People's Republic, modern science and technology and a modern education system became the prime concern of the government. Following the Soviet Union, China in the 1950s promoted research and development in industry and in defence under a highly centralised ruling system. With the introduction of a new policy in 1978, the slogan 'science & technology is the chief productive force, knowledge and talent shall be respected' was popularised. For the first time in Chinese history, science and technology was considered as a main force for economic development. The Government of China, being smart, started shifting from the old Soviet style technology system and came up with a new system that encouraged all parties to participate, including research institutions, universities and enterprises. This overarching national development strategy was defined as 'Rejuvenating China by Technology & Education'.

China came up with a new science and technology development objective (2006-2020) covering not only industry and agriculture but also basic and hi-tech research (China State Council, 2006). It is quite evident that in order to promote its overall strategies and objectives for the social and economic development of the nation, China positively adjusted its science and technology strategies. There are three main roles which science and technology plays in current Chinese society. Basically, the growth of science and technology is a radical move towards social and economic development. Secondly, it is seen as a foremost priority as transformation in economic development can be accelerated by scientific innovation. Thirdly, science and technology are not only related to knowledge and skill in sciences, but also, deal with the spirit and culture of the nation, which are mainly responsible for its future and vitality.

With the passage of time, many policies have been formed to lay the foundation for independent agencies of science and technology which help in constructing an efficient top-down science system in China. Fiscal appropriations for science and technology are granted through programme-based competitive grant schemes, which are administered by the Chinese Academy of Science (CAS), the Ministry of Science and Technology (MOST), the Chinese Academy of Engineering (CAE) and the National Natural Science Foundation of China (NNSFC). The 10 main programmes are covered by competitive grant schemes and every programme includes many subsidiary programmes. These 10 programmes are Basic Research Program, S&T Basic Conditional Construction Program, Key Technologies R&D Program, Torch Program, Spark Program, Innovation Fund for Small Technology-based Firms, National New Products Program, Agricultural S&T Transfer Fund, International S&T Cooperation Program and Special Technology Development. By the end of 2010, China came up with 218 national leading laboratories, most of them being operated by Regional Innovation systems (RIs) and universities, under the administration of the Ministry of Education (MoE) and CAS.

In the last few decades, China has emerged as a science power because of a boom in the Chinese economy. The average annual GDP growth rate of 11.2 per cent in the period 2005-2010 reached ¥47.16 trillion in 2011 (National Bureau of Statistics of China, 2012; Ding, Li, & Wang, 2008; Foray, 2004; P. Zhou & Leydesdorff, 2006). After the United States, China has emerged as the second largest economy and the credit goes to the science and technology growth policies of China.

As any other developing country, the investment in R&D in China has resulted in the progress of science and technology. This investment led to innovations and helped in generating fresh knowledge, which acted as an indicator of increase in gross domestic product. The following table depicts gross expenditure on science related research and development (GERD) in China from 2005 to 2010.

Table 1: Gross expenditure on science related R&D (GERD) in China

	2005	2006	2007	2008	2009	2010
GERD (billion yuan)	245.00	300.31	371.02	461.60	580.21	706.26

2.1 STEM in the Business Sector

Enterprises in China have flourished because of gradual changes in policy. And e and technology indeed is responsible for the growth of these enterprises as the market economy clearly reveals the contributions made by it in the national economy. The competition amongst the enterprises is the result of innovation in science and technology. Many types of cooperation are promoted to build up strong relations between industry and academia e.g., informal consulting by university researchers to industry, joint research projects, technology service contracts, patent licensing, and science parks. Universities and RIs-affiliated enterprises have been promoted to strengthen the close ties between industry and academic institutions. A strong information channel and entrepreneurship training, help in nurturing local companies and here the main role is that of the universities which lay stress on effective Chinese science and technology.

2.2 STEM in the Education Sector

China has always given importance to science and has considered it necessary for growth and development. In China, formal education has two categories: basic and higher. Basic education includes three years of pre-school and twelve years of primary and secondary schools. These junior secondary graduates are required to clear an entrance examination for achieving general senior secondary level where they can continue their studies in general and academic route. This examination evaluates Chinese and other foreign languages, politics (open book), mathematics, chemistry and physics. At the senior secondary level there are two streams: arts and science. Students need to opt for one at the beginning. In most Western countries, students have the right to opt for any particular subject at the senior secondary level. However, not so in China. Here, students have to study chemistry, biology and physics as compulsory subjects in the last year as they have to prepare themselves further for the competitive National College Entrance Examinations (NECC) through which students are enrolled for Higher Education Institutions (HEIs). Mathematics, being an important subject, is compulsory in both streams.

Nation-wide statistics of the number of students enrolled in both divisions is not available and that has made it difficult to find out the clear picture of science students in the higher education sector. However, a rough idea can be made by taking the number of applications filled for both NECC streams. In 2010, 8.9 million students took the NECC, out of which 3.9 million opted for arts and humanities and 4.9 million for science and technology. The ratio of science to arts is 1.26 which proves that science as more popular with students.

Table 2: Applicants of student NECC in both divisions (2010)

Division	Total (persons)
Arts and humanities	3,917,040
Science and engineering	4,897,524
Others	113,095
Total	8,927,659

Source: China Educational Statistics Yearbook, 2010

In the year 2010, a total of 12,656,132, students enrolled for the Normal Bachelor Course, while 6,356,936 got enrolled for

STEM-related areas like science, engineering, agriculture and medicine. In the same year, the number of students who started a course at the bachelors' level was 3,512,563. The ratio of STEM-related field to other bachelor-level course is: 9.8 percent in science, 31.6 percent in engineering, 1.8 percent in agriculture and 6.3 percent in medicine. As compared to students of Australia, Chinese students are more inclined towards science. Post-graduate studies are run in the form of master and doctoral courses in China. Chinese students are more inclined towards science programmes as evident by participation of students of Shenghai (representing mainland China) in PISA 2009. It secured the highest average results in both science and mathematics. Moreover, there was no remarkable performance difference between boys and girls. Maybe India should again start participating in PISA and learn about its own weaknesses.

Table 3: No. of students enrolled in Normal Bachelor Course by field of education (2010)

Field of Education	Number
Science	1,251,280
Engineering	3,995,779
Agriculture	226,030
Medicine	883,847
Others	6,299,196
Total	12,656,132

Source: Ministry of Education, 2012

In western universities, students can choose two different types of master programmes, but in Chinese universities, all master programmes offer some credits for course work. The total number of students enrolled for both master and doctoral programmes in China was 538,117 in 2010, and out of them 267,033 opted for science-related areas.

Table 4: Entrants of Masters' and Doctors' Degree by field of education (2010)

Field of Education	Doctor's Degree	Master's Degree
Science	12,216	46,172
Engineering	23,977	129,727
Agriculture	2,831	12,043
Medicine	6,524	33,543
Others	18,214	252,930
Total	63,762	474,415

2.3 Teaching and learning in STEM

Science is very popular in China and its teaching and learning process under the influence of tradition and culture has given it particular features which are unique e.g., it focuses on theory; it is national examination oriented, teacher centreed and homework supplemented. It involves the student in activities even after classes. There is active participation of parents too. Teachers are trained prior or during the service so that they can give importance to lesson planning and sharing of experiences. The methods and characteristics of STEM-related subjects are studied in three ways that is curriculum, teaching pedagogy and the examination system. This study will help in getting a rough idea of current Chinese science education at the senior secondary level. Generally, just one subject is taught by science teachers. They rarely teach any other subject from the science realm apart from the fact that in urban schools, the teachers generally specialise in one or two subjects each year. Most Chinese math and science teachers have degrees in their own discipline. During the period 2005-10, there was a gradual increase in the number of STEM-related teachers. Most of them were in math, a few in physics and chemistry and still fewer in information technology and biology.

2.4 International Comparisons of Students' Achievements in STEM-related Subjects

When Chinese students compete for international-level examinations like PISA, the success of STEM-related education gets proved. For example, when Shanghai, representing Mainland China, took part in PISA 2009, it scored the highest average results in both science and mathematics. Moreover, if the achievements of boys are compared with girls, there is no remarkable difference (Shanghai Academy of Education Science, 2009).

2.5 Special Programmes for STEM Talents

Under the special education programme, the Science Experimental Class (SEC) is conducted in most of the important senior secondary schools of China with the purpose of honing the skills of talented students. Outstanding students having a high interest in natural science learning are selected and their natural talent in science and research is nurtured. This SEC has a uniquely designed curriculum which is different from the common Senior Secondary Education curriculum.

2.6 STEM in Higher Education and Research Environment

China's transformation from a manufacturing based economy to an innovation and knowledge-based economy is due to the high advancements and growth in the research and development fields of science and technology. China has jumped from the middle income trap to the high income economy by way of bridging the gap between basic research and its commercialisation. China's trajectory can be determined by the environment of research at Chinese institutions of higher education. The Government of China gives a lot of importance to innovative and creative research as it knows its importance for the economy and for this, it has taken great measures in the last three decades to improve research levels at institutions of higher learning The number of universities in China has increased by more than 50 percent, i.e., from 1,792 to 2,560. Approximately 1,200 Chinese higher education institutions can award undergraduate Bachelor of Arts degrees; others can offer vocational and technical education.

In last three decades, China's science and technology work force has increased manifold because of the increase in the number of STEM graduates. In 2010, degree-level programmes were provided by 1,428 HEIs. Out of these, 316 were RIs offering post graduations. The other 1,112 were universities and colleges, of which 320 were natural science and technology universities, 261 were comprehensive universities, 41 agriculture institutions, 7 forestry institutions, and 101 medicine and pharmacy universities. An expansion of HEIs was observed from 2007 to 2008, the reason being an increase in the number of comprehensive universities and natural science and technology universities. The number of agriculture and forestry universities and RIs remained the same during 2005 to 2010.

The results in 2017 were quite shocking as it was found that the number of graduating students had increased 10 times in Chinese universities in the last 20 year period, while in American universities, it doubled in the same period. Around eight million students graduated from Chinese universities in 2017. Approximately 313,000 students were enrolled in doctoral programmes in 2014, apart from 1.5 million in M.A. programmes; out of these 58 percent (182,000) were science or engineering Ph.D. students, and 44 percent (666,000) were science or engineering M.A. students. At present, China has the largest number of laboratory scientists as compared to other countries and its research and development spending outstrips the European Union.

A remarkable increase in scientific publications can be observed in China. The reason for which is the investment made by China in higher education and science and technology. In 2003, China had a contribution of 6.4 percent in global scientific papers which increased to 18.2 percent in 2013 and is next to the US, which has 18.8 percent. From 2003 to 2013, China showed an 18.9 percent average growth rate every year in scientific papers, which is twice that of the United States. The quality, however, is still debatable when measured by percent share of China's scientific papers. It was observed that only one percent of these papers are referred throughout the world, which proves that quality has progressed less as compared to quantity. Though the share of citations has increased from 0.5 percent in 2002 to 0.8 percent in 2012, yet it is less than that of the US, which increased from 1.76 percent in 2002 to 1.94 percent in 2012.

A science and technology qualification from higher education institutes of China opens many new opportunities as one can be a part of the great work force of China i.e., from math and science teachers to engineering and technical professionals, from medical professionals to government science advisors and then from agronomists to researchers. These HEIs of China help in the growth and development of technology industries as they provide them with talents, or sometimes they directly work and contribute with research and development activities.

2.7 Vulnerabilities in the Current STEM System at HE Level

Progress in China's higher education system can be observed from the fact that the number of students have increased many fold in science-related fields and are publishing academic and research papers in not only domestic but also in international science and technology journals. But if we talk about a progressive STEM system, it cannot be defined only by the increasing number of students or increasing research output, as it is not only concerned with quantitative, but also qualitative aspects. When the qualitative aspect was analysed closely, vulnerabilities were observed in Chinese academic research. The main reason for such vulnerabilities was that in China, STEM subjects are taught in ways very similar to science subjects at the senior secondary level. Science queries bring uniform and normative answers and only fundamental knowledge and skills are emphasised. This narrow perspective defeated the goal of higher education, resulting only in the teaching of scientific facts in place of developing scientific attitude and spirit among the learners. Science is not the ultimate truth, it is just an instrument. Chinese HEIs did not focus on this.

2.8 Strategies for Facilitating STEM in Higher Education Sector

For the national and economic development of a nation, even including its overall competitiveness and progress, science and technology plays a major role. The higher education sector is facilitated through various strategies of the Chinese government as it is an indispensable part of the National Science and Innovation system. It is launching projects across the nation, initiating progress in different fields and providing policy support. The objective of the section is to study important strategies for the promotion of science education in universities, including elite universities.

3. Summary on National Strategies for Promoting STEM in HE Sector

The Science Reform and Practice Program in 2005 launched by the Ministry of Education, targeted improvements in evaluation of science education, diversification of the cultivation of science and technology talents, co-construction of science curriculum, and management of science education in universities. This programme comprises of 14 subsidiary programmes, covering the construction of national model base for science and technology talent cultivation, intensifying the collaboration between industries and universities/RIs and fostering application-oriented manpower, executing English-teaching science programmes and evolving the evaluation system for science education in universities jointly with industrial associations. The information, biology, materials and energy fields (Ministry of Education, 2005) have been considered of prime importance. In the current scenario, Chinese universities have become much more autonomous in the recruitment of students and in the designing of programmes. Almost all outstanding universities, which are at top level and give prime importance to research, have started special programmes for excellent students in science and technology. Students enrolled in special science and engineering programmes have gone through an entirely different route when compared with ordinary students.

Autonomy is granted in recruitment as well as in management of these special programmes of science and engineering. A supervisor is allocated to each student for all four years. However, in general courses, personal tutors are provided only in the last year to guide them while writing their dissertations. The supervisors provided to the students of the special programmes have extensive knowledge of their field and are generally very senior professors or academic staff who can support the development of students in the best possible way. In the case of special programmes, students are provided the right to select double majors for study, and, it is observed that the ratio of graduating students pursuing a Masters' degree in a special programme is higher than that of other courses.

3.1 STEM Personnel and Employment

China has emerged as one of the biggest reservoirs of research and development. From 2005 to 2010, the number of engineers and scientists has approximately doubled. Out of 3-5 million people performing various types of research and development, 20 percent are with higher degrees in research and 62.1 percent are full time researchers. China is bridging the gap, yet the density of research in China is not at par with many developed countries. In comparison with France, Japan and Germany, where research and development personnel were 1,490, 1,390, and 1,310 (OECD 2011a) respectively, China had 336 personnel per thousand employments in 2010. However, this low density points towards great scope for improvement. For this, China is expanding HEIs rapidly so that youth get educated and contribute to science and technology growth as per National Mid and Long-Term Education Reform and Development Framework (2010 to 2020). The Government of China has set a target of 40 percent gross enrolment rate for Higher Education sectors by 2020 and it has also been targeted that by 2020, 90 percent of the new labour force should be awarded HE degrees (Ministry of Education 2010). One point which needs to be paid attention to is that only 25.3 percent females are among R&D personnel, which is much lower than their male counterparts. It shows that in science and technology females are lagging behind. As the government is trying to raise the density of science and technology personnel, if it looks into the issue and starts exploring female talents too, there are much more chances of progress.

3.2 R&D Personnel (2005-10)

China in 2004 awarded engineering degrees to 43 percent of total students enrolled, which is very high but it reduced to 32 percent in 2012. Other countries where such high proportion of engineering degrees are awarded are Iran, Taiwan, South Korea, Japan, Mexico, Finland, Columbia, Singapore and Indonesia. Out of the total Bachelor degrees awarded in the US and other countries, 12 percent are in like biology, physics, computers, agricultural sciences, statistics and mathematics

Between 2000 and 2012, it is observed that the number of science and technology university degrees awarded in Taiwan, Turkey, Germany, China and Japan have either doubled or more than doubled. However, in Australia such degrees increased by two-thirds and in the US and Poland by nearly 50 percent. In Japan, France and Spain, there is a decline and degrees awarded were 10 percent, 24 percent and 3 percent less respectively during the same period. More natural science and engineering degrees are observed in China, which resulted in an increase of science and engineering university degrees; approximately 1.3 million, up more than 300 percent from 2000 to 2012.

China has performed an appreciable task by reforming action, especially science education and science and technology policies, however, vulnerabilities are observed at secondary as well as Higher Level Science Education. Hence, China is working for bringing reformation and improvements in science education and at the same time must keep on expanding Higher Education Sector. Science education is the base of the complete higher education system therefore

Table 5: First University Natural Sciences and Engineering Degrees, by selected country, 2000-12 (in thousands)

Year	China	USA	Japan	Germany	Mexico	South Korea	Taiwan	United Kingdom
2000	281.27	210.45	136.96	41.39	48.87	72.84	34.32	70.47
2001	302.09	211.84	137.72	38.55	52.38	79.45	42.86	78.43
2002	347.01	219.58	139.44	38.79	56.93	80.93	55.26	78.23
2003	484.70	233.86	136.88	41.20	67.32	80.10	66.05	79.87
2004	610.71	238.31	134.02	46.61	54.43	84.37	72.28	70.91
2005	715.72	239.61	133.21	50.24	61.03	84.36	78.13	70.68
2006	807.18	242.19	132.50	61.68	65.79	83.12	81.77	69.97
2007	905.10	244.55	131.81	69.64	64.71	83.13	85.16	67.93
2008	1,001.86	247.51	130.42	79.98	63.61	92.33	85.70	68.31
2009	1,074.98	252.51	129.27	88.59	65.35	89.85	81.54	68.23
2010	1,130.71	264.56	125.11	95.26	81.23	88.95	80.97	70.73
2011	1,214.79	280.62	125.58	102.64	91.25	93.42	80.38	74.18
2012	1,312.43	302.29	123.05	105.07	97.14	92.19	80.97	78.20

Sources:https://www.nsf.gov/statistics/2016/nsb20161/#/report/chapter-2/international-s-e-higher-education. (Natural sciences here include agricultural sciences; biological sciences; computer sciences; earth, atmospheric, and ocean sciences; and mathematics.)

much attention is required to be paid to it. Science and technology innovations are the ones on which the competitiveness of the nation depends and for this human resource is a prime need. To sustain the growth and development of science and technology, many specialised talents are trained through it. Science education is of utmost importance for other major's learning. The scientific literacy and civilisation of the whole nation depends upon the methods of science education. As compared to developed countries in the West, science education in China attracts more participants both at Secondary and Higher Education level. In China, teaching and learning of basic science subjects and mathematics are given due importance which helps in building the foundation of Chinese students which eases further specialised science learning and research. It can be concluded that in the near future China can emerge as the World's Science Giant.

4. STEM – USA versus China

Just before this present generation, China was at the bottom in most international rankings of nations in the fields of science, education, technology and innovation. But after an investment in human capital for two decades, China emerged as a global competitor. Now, it is the envy of most and in most ways performs even better than the US. The Programme for International Student

Assessment i.e., PISA is an internationally recognised gold standard which compares educational performance of high school students. In the 2015 PISA test, the US was ranked 39th in mathematics, China was placed at sixth. The score of the US was very low, while China's score was above the OECD level. Even the highest-rated state, Massachusetts would have stood 20th if it were measured as its own country in the rankings – a drop from its ninth place rating when the test was last conducted in 2012. As per a recent survey done at Stanford University related to the comparison of students opting for engineering and computer science in college, graduates of a Chinese high school **come with a three-year advantage over American students in critical thinking skills**.

To become the number one university for engineering in the world, the Tsinghua University in 2015 passed MIT in world report rankings and US News. China and the US had four out of the top 10 schools of engineering. In the case of STEM subjects, which provide core competencies and drive advances in technology and science, and are the fastest growing sector of modern economies, **China is leading in terms of quantity as four times more graduates are produced by it each year as compared to the US (1. 3 million versus 300,000). Chinese students who enrolled in American universities have been excluded from this data.** This gap continues to persist even after the Obama Administration's initiative which celebrated 'Educate to Innovate' in 2009 with the objective of promoting STEM education. Every year, more Ph.D. degrees have been awarded to Chinese students in STEM fields as compared to American students.

5. STEM in European Union

European countries have also taken many initiatives to promote STEM education; specifically at the tertiary level. The most recent European Union (EU) tertiary data gives a rather varied picture of the share of STEM graduates out of the total number of graduates across member states. While the STEM graduate share remained more or less stable from 2007 to 2012 (around 18–19 percent) at the EU level, there were significant variations at the country level. Germany was in a lead position, with 28.1 percent that graduated in a STEM-related discipline in 2012. In second rank came Sweden, Greece, Finland and Romania respectively, with shares of STEM graduates exceeding 22 percent. At the other end of the spectrum, we find The Netherlands and Luxembourg with around 10 percent. However, alongside the differing characteristics of national economies, the variation in the total number of graduates as a share of the relevant population needs to be factored in interpreting this indicator.

From 2007 to 2012, the share of STEM graduates increased in 13 countries, decreased in 13 countries and remained unchanged in one country. These developments should be seen in a context of where there was a general expansion of higher education systems in the EU as well as globally. The figures, therefore, illustrate the overall perceived attractiveness of STEM studies in comparison with other tertiary fields of study. Several member states experienced a rather insignificant increase or decrease. Ireland saw the largest increase in STEM graduate share, from 9.4 percent to 19.8 percent, while Austria accounted for the largest decrease from 27.6 percent to 20.9 percent. Some countries have seen rapid increases in graduation rates because of the Bologna Process (A series of ministerial meetings and agreements between European countries to ensure comparability in standards and quality of higher education qualifications. The process has created the European Higher Education Area under the Lisbon Recognition Convention) and the harmonisation among systems of higher education in European countries and a general shift away from long programmes towards three-year programmes (Deiss & Shapiro, 2014). In absolute terms, the total number of STEM graduates increased from around 755,000 in 2007 to 910,000 in 2012 at the EU-level, corresponding to an average annual 3.8 percent growth rate and an overall 20 percent increase over the period. In comparison, the share of STEM graduates in the USA was at 14.6 percent in 2012, but the absolute number of STEM graduates increased from around 386,000 to 482,000 from 2007 to 2012, with an average annual growth rate of 4.6 percent

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Chapter 6: Emerging STEM Domains and New Job Opportunities

The employment market all over the world is witnessing a complete change in terms of job profiles and skills required. With fast paced advancement of technology, new equipment, application software packages, mobile applications and human-friendly gadgets are being introduced to make life more comfortable. On the other hand, there is emphasis on protecting the environment and ensuring sustainable development so that future generations are not starved of natural resources with increase in population. Reliance on fossil fuel for energy is being replaced by non-conventional methods of generating energy to safeguard against environmental pollution and arrest spiraling costs. Science, Technology, Engineering and Mathematics (STEM) are leading to the creation of new jobs due to which even existing employees are required to acquire new skills to remain relevant.

1. International Scenario

Thirty STEM occupations utilising most STEM skills have been identified by a study conducted in UK to meet supply and demand of high STEM skills (2013). These ranged from mathematicians, chemists, computer hardware and civil engineers to astronomers, agricultural and food science technicians and statisticians. All 30 also fit into occupational categories given in the International Standard Classification of Occupations (ISCO). These are: science and engineering professionals, information and communications technology professionals and science and engineering associate professionals.

1.1 Science and Engineering Professionals

Main activities: Conduct research, improve or develop concepts, theories and operational methods; or apply scientific knowledge relating to fields such as physics, astronomy, meteorology, chemistry, geophysics, geology, biology, ecology, pharmacology, medicine, mathematics, statistics, architecture, engineering, design and technology.

Occupations in this group are classified into the following minor groups:

1. Physical and Earth Science Professionals. Examples: Astronomer, Medical Physicist, Nuclear Physicist, Physicist, Climatologist, Hydro-meteorologist, Meteorologist, Weather Forecaster, Chemist, Biochemist, Geological Oceanographer, Geologist, Geophysicist, Geoscientist, etc.
2. Mathematicians, Actuaries and Statisticians. Examples: Actuary, Demographer, Mathematician, Statistician, Operations Research Analyst, Data Scientist, etc.
3. Life Science Professionals. Examples. Animal Behaviourist, Bacteriologist, Biologist, Biomedical Researcher, Biotechnologist, Botanist,

Microbiologist, Zoologist, Molecular Geneticist, Molecular Biologist, Agronomist, Soil Scientist, Fisheries Adviser, Forestry Adviser, Forestry Scientist, Air Pollution Analyst, Ecologist, Park Ranger, Water Quality Analyst, Conservation Scientist, Environmental Adviser, Environmental Research Scientist, etc.

4. Engineering Professionals. Examples. Industrial Efficiency Engineer, Industrial Engineer, Industrial Plant Engineer, Production Engineer, Civil Engineer, Geotechnical Engineer, Structural Engineer, Metallurgist, Aeronautical Engineer, Engine Designer, Mechanical Engineer, Chemical Engineer, Fuel Technologist, Plastic Technologist, Refinery Process Engineer, Extractive Metallurgist, Nuclear Power Generation Engineer, Quantity Surveyor, etc.
5. Electro Technology Engineers. Examples: Electric Power Generation Engineer, Electromechanical Engineer, Computer Hardware Engineer, Electronics Engineer, Instrumentation Engineer, Telecommunications Engineer, Broadcast Engineer, etc.
6. Architects, Planners, Surveyors and Designers. Examples: Building Architects, Interior Architects, Landscape Architects, Urban Planner, Costume Designer, Fashion Designer, Industrial Designer, Jewelry Designer, Land Planner, Aerial Surveyor, Cadastral Surveyor, Cartographer, Computer Games Designer, Digital Artist, Graphic Designer, Multimedia Designer, Website Designer, etc.

1.2 Information and communications technology professionals

Main activities: Conduct research, plan, design, write, test, provide advice and improve information technology systems, hardware, software and related concepts for specific applications; develop associated documentation, including principles, policies and procedures; and design, develop, control, maintain and support databases and other information systems to ensure optimal performance, data integrity and security. Occupations in this group are classified into the following minor groups:

- Software and Applications Developers and Analysts. Examples: Computer Scientist, Information System Analyst, System Designer, Business Analyst (It), Programmer Analyst, Software Designer, Software Developer, Software Engineer, Website Developer, Website Architects, Multimedia Programmer, Applications Programmer, Software Tester, Quality Assurance Analyst, etc.
- Database and Network Professionals. Examples: Data Administrator, Database Administrator, Database Analyst, Database Architect, Network Administrator, Systems Administrator, Network Analyst, Digital Forensic Specialist, etc.

1.3 Science and Engineering Associate Professionals

Main activities: Perform technical tasks connected with research and operational methods in science and engineering. They supervise and control technical and operational aspects of mining, manufacturing, construction and other engineering operations and operate technical equipment, including aircraft and ships. Occupations in this group are classified into the following minor groups:

1. Physical and Engineering Science Technicians;
2. Mining, Manufacturing and Construction Supervisors;
3. Process Control Technicians;
4. Life Science Technicians and Related Associate Professionals;
5. Ship and Aircraft Controllers and Technicians.

Some associate professionals are also included: Information and Communications Technicians. They provide support for day-to-day running of computer systems, communications systems and networks, and perform technical tasks related to telecommunications, broadcast image and sound as well as other types of telecommunications signals on land, sea or in aircraft. Occupations in this group are classified into the following minor groups:

- Information and Communication Technology Operators and User Support Technicians;
- Telecommunications and Broadcasting Technicians.

2. Jobs in India Linked to STEM Education

India is a developing nation, gradually carving its position among top nations of the world. The prime challenge in front of this nascent power is the science education of its sizeable young population. A bulk of Indian inhabitants still reside under reasonably challenging circumstances. Under such situations, academic organisations maintaining pace with scientific and technological advances is a challenge in itself. Most notably, incorporating most recent advances in STEM into their core curriculum in a holistic manner, thus ensuring both learners' employability as well as social growth is a prime challenge.

STEM is important because the economy and the general wellbeing of a nation is all backed by science, technology, engineering, and mathematics. Thus, STEM, is not just coding and lab coats. It is the keystone of manufacturing, food production, healthcare, and so much more than that: we might take it for granted, but surely can't survive without it. Emerging technologies which will drive demand over the next 10 years are – Artificial Intelligence, Machine Learning, IoT, Augmented Reality, Virtual Reality, Cloud, Big Data, Blockchain, Clean-Tech, etc. Space Tech is another upcoming area that is setting its baby steps initially but will wholly emerge after 15-20 years.

With Artificial Intelligence, a lot of low-level backend jobs will be automated. So, one can imagine that low-level jobs which have been outsourced from Western countries to India will no longer be available. This could have a huge impact on the Indian economy. It becomes increasingly crucial for India to impart Artificial Intelligence and related skills to its job force because, with the event of this e-revolution, the nature of job opportunities will also change. Machine Learning Engineer, AI Lawyer, IoT architect, Cyber Risk and Resilience Management, Cloud Liasioning and Quantum Programmers are a few core positions already much in demand in

IT jobs overseas. Their counterparts are what the industry is on the lookout for in STEM engineers. Technology-supported advances like educational gaming, online virtual laboratories, technology-supported cooperation, real-time seminal evaluation and skills-based evaluation can improve STEM education in many diverse ways. Some of the emerging technologies which have the potential to create new jobs that are STEM driven are mentioned below.

2.1 Robotics

Robotics is an interdisciplinary branch of engineering and science which includes disciplines like mechanical engineering, electronics engineering, computer science and others. Robotics encompasses everything to do with design, engineering, programming, testing and development of robots – machines designed to perform tasks currently or previously performed by humans. Robotics is growing rapidly with the advent of big data and IoT. IoT machines are now capable of processing large quantities of data and learning with minimal human interaction. Using autonomous vehicles as an example, sensors on a vehicle process thousands of data points each second along with location data from the web to move the vehicle safely along its route. Robotics projects and applications can be found across many industries from automotive production to military drone operations to landing on and exploring Mars. There are many fields in which robots are used, ranging from disaster management, defence, search and secure operations and even electronically-operated toys.

The methodology of evolutionary robots uses evolutionary computation which helps in the designing of robots, especially their motion, behavior control and body form. As it happens in natural evolution, there is competition among a large number of robots. This competition judges the fitness of robots. By using robot simulation software package, this technique may first run entirely in simulation and when the evolved algorithms are found good enough, then it is tested on real robots. At present around 10 million industrial robots are working around the world. Japan is at the top in utilising robots in its manufacturing industry. The Defense Advanced Research Project Agency (DARPA) along with Boston Dynamics is working to form a series of robots designed for 'disaster relief,' and the same technology can also be used in a combat role too. A lot of effort is being put in for applying the fruits of AI and Big Data to current industrial robots, with companies like Embodied Intelligence, Kindred, Ocado and Amazon working on dexterous and dynamic machines for warehouses and assembly lines. Such advancements can be a big boon for industries. Interestingly, in October 2017, a robot named Sofia was given citizenship of Saudi Arabia at the technical Summit Future Investment Initiative (FII).

Such intelligent robots can replace human resources because they are easy to afford and they ensure improved financial returns. In the case of robots, when compared with human resource, there are no problems related to strikes, sickness, absence, overtime, claims, recruitment difficulties, wage demands, transport, housing, pensions, etc.

2.2 Metal Printing

Various branches of manufacturing and production have been revolutionised by recent growth and development of three dimensional printing technologies. This 3D printing is not only cost-effective but also maintains high quality as its manufacturing process involves less labour and high precision. The requirements of a diverse population can be fulfilled by using this 3D printing technology as in-house 3D printers can be used for manufacturing of car accessories, printing of human organs and tissues as well as for micro-batteries and many other applications. These printers are effectively used in hospitals and clinics for 3D printing of tooth fillings, skin tissues and body organs. 3D printing involves the process of additive manufacturing which has made it a resourceful technology in the repair and service of components of space stations or space shuttles in outer space, which otherwise is very challenging. 3D printing technology has advanced to the extent that it can print micro-batteries to provide power to small incest drones which are used in confidential operations. All this proves that 3D printing is the embodiment of the current manufacturing process.

MIT maintains that 3D printing can be useful for the entire manufacturing industry as it provides an easy and less expensive practical way to manufacture parts. Many leading companies like GE, Desktop Metal and Mark Forged have come up with 3D metal printers which can help manufacturers reduce requirements for large inventories and can customise print material as required.

This year, MIT researchers succeeded in 3D printing of genetically programmed bacterial cells, compatible with most hydrogels. Utilising this breakthrough, they printed 3D 'living tattoos' that act as sensors and respond to outside stimuli. While the research is still in its early stages, keep an eye out, for this technology to evolve in the near future. 3D printed bacteria have potential applications in the medical field and in the development of wearable materials and interactive displays.

3D printing metals means not only prototyping but also printing objects that will actually go into use. Unfortunately, metals have long been prohibitively costly to print. In mid-2017, engineering-driven start-up Desktop Metal, unveiled a desktop printer that can reportedly print metal a hundred times faster and 10 times cheaper than its current competitors. Going forward, the company is offering two systems: a studio system designed for rapid prototyping and a production system designed for manufacturing.

2.3 Automation

The use of control systems like computers or robots and information technologies in industry for handling different machineries and processes as replacement for human beings is known as Industrial Automation. After mechanisation, this is the second step which has great scope for industrialisation. The scope of automation earlier was only to get more production and to decrease costs associated with human resource, but now attention has been drawn towards increasing flexibility and quality in the manufacturing process. Manufacturing flexibility not only allows for more product types, but also lets consumers order customised products that are automatically produced. With advancements in technology, these automated systems have become an important part of organisations, especially when tasks are practically impossible, dangerous or tedious for human beings. In recent years, the process of automation of vehicles has started, which has had a substantial impact on the environment. However, this impact depends on several factors and hence can be harmful or beneficial. Since these automated vehicles are less accident prone when compared to human driven vehicles, some precautions like laminated glass or anti-lock brakes built into current models are not needed for such self-driving versions. With unnecessary features removed, the weight of the vehicle gets reduced significantly, which results in reducing fuel consumption and emission per kilometer. Emissions are further reduced because of the precision with which self-driving vehicles accelerate. These self-driven vehicles, with the help of fuel efficient features, automatically calculate and take the most efficient roads.

Cognitive automation which is an upcoming form of automation is enabled by cognitive computing. Its main concern is the automation of clerical tasks and work forces that comprise of structuring unstructured data. Cognitive automation depends upon many disciplines like machine-learning algorithms, big data analytics, natural language processing, real-time computing and evidence-based learning. According to Deloitte, '**Cognitive automation helps in the replication of human tasks and judgment at fast pace and considerable scale**.' However, this advancement in automation has made workers feel anxious as they now fear losing their jobs because technology can replace their skills and experience. This automation has already started contributing to unemployment, especially in nations where the government is not taking any action to reduce its impact. In a research undertaken by Carl Bendikt and Michael Osborne, it has been observed that by 2033, 47 percent of the current jobs in the United States may become fully automated.

2.4 Infrastructure Development

Infrastructure development is often confused with the term 'Construction'. But both terms are different. Infrastructure development involves fundamental structures that are essential for the functioning of a community or society. It includes roads, water supply, sewers, electrical grids, telecommunications, renewable energy, purification systems for potable water, waste management and so on. The concept of 'Smart City' is a new term in the field of Infrastructure development. The idea of a 'Smart City' is based on the fundamental rule of 'Less Space and More Efficiency in a Sustainable Manner'. To fulfill the concept, a lot of technical planning, design, executing and implementation is involved. The role of civil engineering in the field of infrastructure development needs no explanation.

A 'Smart City' is an urban region that is highly advanced in terms of overall infrastructure, sustainable real estate, communications and market visibility. As the smart city is a trend to some and a necessity to others, it is obvious that with demographic explosion in cities, we have to rethink our way to live with limited resources to consume. As a civil engineer, one needs to ensure sustainable and rational increment in growth and keeping a balance between supply and demand.

2.5 Climate Change and Global Warming

Climate change refers to seasonal changes over a long period with respect to the growing accumulation of greenhouse gases in the environment. It is highly important to tackle this phenomenon, given the pivotal role it plays in the formation of natural ecosystems and its interdependent financial economics and social stability. Thus, sustainable development, both at the regional and global levels, is highly dependent on consideration of the effects of changing climate. Several parts of the world are already experiencing high temperatures, change in rainfall patterns, sea level rise, increase in intensity and duration of storms, etc.

Thus, it is imperative to educate budding civil engineers about climate change by explaining to them the physical science of climate change, its causes, trend of climate data, global climate models, global circulation models, IPCC scenarios, vulnerability and risk associated with climate change, climate future projections and assessment techniques for evaluation of the impact of climate change on key sectors like water bodies, agriculture, urban planning etc., and adaption planning and management, including climate resilient developments.

2.6 Inland Water Transport

In water-based transport, fuel costs are low and environmental pollution is lower than transport by road, rail or air. The waterway is naturally available. However, it has to be maintained and upgraded. Navigation based on inland waterways – rivers, canals, lakes as well as tidal rivers is practiced extensively in developed countries like Germany (20 percent), USA (21 percent) etc., whereas in India inland transport constitutes only 0.15 percent of the transportation sector. There has been huge investment of thousands of crores by the Indian government in the area of Inland Water Transport (IWT) in recent years and the National Waterways Authority of India (NWAI) has declared the development of 111 national waterways in coming years. Therefore, it is very essential to train civil engineering students in inland navigation, teaching and training them about different national waterways in the country, navigation channels, lock gates, construction of jetties, and building of embankments to create port terminals, navigational aids for movement of vessels and water traffic management.

2.7 Remote Sensing and GIS (Geographical Information System) in Smart City Concept

An RS and GIS-based centralised information system provides an IT Framework which supports the maintenance and deployment of data and applications for every aspect of the city development life cycle.

1. **Acquire:** Appropriate sites can be found with the help of RS and GIS for city development, correct legal boundaries observed, and proper valuation of new or existing sites arrived at.
2. **Planning and Design:** Identify deficiencies and provide optimal solutions. GIS is integrated with most design tools including Computer Aided Design (CAD) and Building Information Modelling (BIM), bringing better cost estimation and analytical capabilities in the infrastructure design process.

3. **Sell:** Help in understanding how and where to market city developments; improve retention rate and attract tenants and buyers. Analyse conditions of markets along with demographics in order to get a better and precise picture of suitability and need of property.

4. **Maintain:** Easily manage disparate assets. Integrate asset inventory with work order management and inspection history in order to manage the investments in a cost-effective manner.

2.8 RS and GIS in Other Civil Engineering Works

In addition to town planning and urban development, RS and GIS can help in site investigations and in regional planning. Site investigation generally needs geologic and topographic considerations. Such assessments are allowed by remote sensing. In case of landslides, major factors such as structure, slope, geomorphology, lithology, drainage, land use and road network can also be analysed by using RS and GIS tools for developing early warning systems. In the process of designing and planning of highways, GIS is an important tool for least cost highway alignment. For getting optimum highway route alignment which is suitable, compatible and economical with the environment, many types of data need to be taken into consideration with the help of GIS tools. Terrain evaluation can help in assessing the performance of the terrain for particular developmental activities. Either RS data or the Digital Terrain Model (DTM) can help in acquiring or generating terrain information. GIS tools are of great help in the timely detection of any problem that can result in deterioration of the structure or make it unsafe or even result in its failure. In water resources engineering, by analysing multi-date RS data, it is possible to monitor river morphology, erosion, sediments deposit and soil moisture condition. Groundwater pattern and assessment can also be performed using these tools. RS and GIS are important tools for flood mapping and flood loss assessment.

2.9 Big Data and Hadoop

People generate information every day, whether they are driving their cars, shopping online, browsing the Internet or attending class. Today, data size is increasing tremendously. For example, VISA handles around 172,800,000 card transactions every day. There are more than 6,840 tweets per second on Twitter. Big Data is the collection of data sets which are huge and complex, and or difficult to store and process by using available database management tools or by traditional data processing applications. Recently, many Big Data technologies have come up to process and manage such large volumes of data. Hadoop is an open source, scalable and fault-tolerant framework from Apache Software Foundation (ASF), and is coded in Java. Hadoop is a storage system which stores and processes data as well. Hadoop works on many machines simultaneously and hence it provides parallel processing of data. We can take big data from any source and analyse it to find answers that enable:

1. Cost reductions;
2. Time reductions;

3. New product development and optimised offerings; and
4. Smart decision making.

Many business related tasks can be accomplished by combining big data with high-powered analytics. These are:

1. Determining root causes of failures, issues and defects in near real time;
2. Generating coupons at the point of sale based on customer's buying habits;
3. Recalculating entire risk portfolios in minutes; and
4. Detecting fraudulent behaviour before it affects your organisation.

2.10 Cloud Computing

We have become so habitual to using Cloud Computing that we don't even realise it. When we have a query and type the same into Google, it is neither the computer nor the Messenger that helps in finding out the answer. The word we type gets immediately shuttled over the Net to one of Google's hundreds of thousands of clustered PCs which deliver a result and sends it immediately back to us. When we do a Google search, any computer located in any part of the world, whether in California, Dublin, Beijing or Tokyo may answer the query we have raised. This we either don't know or we don't care. Cloud computing can turn system infrastructure-dependent companies into infrastructure-less companies. It provides Internet-based seamless services to the end user. Exactly where the hardware and software is located and how it all works doesn't matter to the user. These services are provided by some other company and are managed on the end user's behalf. To run an application, the user may require three different types of cloud-based services:

1. Infrastructure as a Service (IaaS): Means buying access to raw computing hardware over the Net, such as servers or storage by paying a monthly subscription or a per-megabyte/gigabyte fee to have a hosting company serve up files for your website from their servers. An example is Amazon Web Services (AWS).
2. Platform as a Service (Paas): Means developing applications using web-based tools so they run on systems software and hardware provided by another company. Google App Engine is an example of PaaS.
3. Software as a Service (SaaS): SaaS is a model of software deployment where an application is hosted as a service provided to customers across the Internet. SaaS alleviates the burden of software maintenance/support, Web-based email and Google Documents are perhaps the best known examples

2.10.1 Advantages of Cloud Computing

1. Improved performance: Computers in a cloud computing system boot and run faster.
2. Reduced software costs: Instead of purchasing expensive software applications, you can get most of what you need for free.
3. Universal document access: Documents are instantly available from wherever you are.

4. **Latest version availability:** When you edit a document at home, that edited version is what you see when you access the document at work.
5. **Easier group collaboration:** Sharing documents leads directly to better collaboration.
6. **Device independence:** You are no longer tethered to a single computer or network.

2.10.2 Disadvantages

1. **Requires a constant Internet connection:** Cloud computing is impossible if one cannot connect to the Internet.
2. **Features might be limited:** This situation is bound to change, but today, many web-based applications simply are not as full-featured as their desktop-based applications.
3. **Stored data might not be secure:** Unauthorised users can gain access to the confidential data.
4. **Stored data can be lost:** Theoretically, data stored in Cloud is safe, replicated across multiple machines. But on the off chance that your data goes missing, you have no physical or local backup.

2.11 Artificial Intelligence and Machine Learning

Machine Learning is a field of study that gives computers the ability to learn without being explicitly programmed. Artificial Intelligence, on the other hand, is not just one technology; it is a broad field constituting many disciplines from robotics to machine learning. The ultimate goal of AI is to build machines capable of performing tasks and cognitive functions that are otherwise only within the scope of human intelligence.

Machine Learning and Artificial Intelligence are likely to be game changers in the coming decades. Presently, 30-35 percent of IT resources are being spent to support the creation of new digital revenue streams, and by 2020, almost 50 percent of IT budgets will be tied to digital transformation initiatives. Enterprises pursuing digital transformation initiatives will more than double the size of their software development teams in a couple of years, focusing new hires almost entirely on digital initiatives.

With the help of AI and Machine Learning, it is possible to automate models which can analyse larger, complex data to return faster and accurate results. The use of algorithms to build a model is helping organisations to bridge the gap between their products and users with better decisions and least human intervention. Most industries with enormous volumes of data have recognised the value of Machine Learning.

Major industries where Machine Learning and Artificial Intelligence are used are:

1. Healthcare and Fitness
2. Sales and Marketing
3. Financial Trading
4. Transportation and Conveyance
5. Personal Security
6. Online Search

Here is a roundup of Machine Learning and Artificial Intelligence trends in 2018 as forecasted by many experts:

1. AI in Everything Digital: Technology vendors vying for space in the advanced apps and analytics market will accelerate their efforts in delivering AI-enabled applications and systems. In other words, AI will penetrate all business models.
2. **Intelligent Solutions for Data Management:** As more and more business apps and BI systems develop enhanced AI capabilities, the popularity of AI-powered business solutions will grow.
3. **Automation of Connected Devices:** Autonomous systems in farming and mining will continue to grow with partially or fully robotic layers, which will end up connecting people, machines and businesses.
4. **Conversational Platforms:** The ability of user interfaces to engage with users will gain popularity in every kind of business application.
5. **Event-driven Business Ecosystems:** Enterprises will gradually adopt event-driven business models, where Cloud, IoT, and mobile will use AI technologies as tech enablers.

AI and ML have been consistent buzzwords in the global IT industry for several years, but presently, Machine Learning and Artificial Intelligence trends show that both will become even bigger market differentiators as we move through 2019 and beyond.

2.12 Mobile Application Development

Recently smart phones and tablets have become very popular and this has resulted in mobile application development which is further helping software creation. These mobile applications, however, are created on the pattern of traditional software development. The result is software intended to utilise the unique features and hardware of mobile devices.

Mobile applications, also known as mobile apps, are software programmes which are developed for mobile devices like tablets and smart phones. These apps have many purposes, ranging from utility, productivity, navigation to entertainment, sports, fitness etc. Mobile apps have also helped in the development and adoption of social media, which has become the most popular field these days.

Mobile apps are created according to the operating system in which they have to run. For example, Apple iOS supports mobile apps for the iPad, hence, the Apple phone cannot run on Google's Android and vice versa. As of now, three major players in the mobile apps space are:

- **Google Play:** for Android devices
- **Apple's App Store:** for iPads and iPhones
- **Amazon AppStore:** for Amazon Fire devices

While the most popular operating systems, iOS and Android, have done an excellent job in standardising the types of mobile app development available for programmers to make, apps can take on a wide range of shapes in the following ways:

- **Native apps:** These are apps created for a specific platform (iOS or Android) using the software development tools and languages supported by those operating systems. iOS uses Xcode and Objective-C, whereas Android uses Eclipse and Java.

- **HTML5 apps:** Based on the near-universal standards of Web technologies, namely HTML5, JavaScript and CSS, this type of mobile app takes a write-once-run-anywhere approach to mobile development. Apps developed in this framework are cross-platform compatible and require only minimal changes to ensure complete functionality in each operating system.
- **Hybrid apps:** These entail the creation of a container developed in the native system that makes it possible to embed an HTML5 app within it. This allows apps to make use of the diverse and unique elements of each native system.

2.13 Cyber Security

In recent years, digital attacks have become common. Cyber security is used for protecting systems, programmes and networks from such attacks. The purpose of such attacks is to access, destroy or change sensitive information, or to exhort money from users, or to disrupt normal workings and processes. The purpose of cyber security is to defend the computing assets of a company against a cyber-attack and protect it from adversaries.

The implementation of effective cyber security has also become very challenging these days, because there are many people who are using devices and attackers have become innovative.

As technology has connected the world, everyone can take benefit from advanced cybersecurity programmes. Cyber-attacks can be very problematic, even for renowned organisations, as they can cause financial loss and damage reputations. If anyone suffers from a cyber-attack, he or she may lose assets, business or reputation, and may have to face regulatory fines and litigation, and costs of remediation. The UK government's Cyber Security Breaches Survey 2017 found that the average cost of a cyber security breach for a large business is £19,600 and for a small to medium-sized business is £1,570. A good cyber security approach can provide many layers of protection for computers, networks, programmes or data that one desires to keep safe. In order to protect any organisation from cyber-attacks, the people, processes and technology all must complement each other in order to form an effective defence system.

2.14 Internet of Things

The Internet of Things (IoT) is defined as a network of physical devices, vehicles, home appliances and other items embedded with electronics, software, sensors and actuators which connect and exchange data creating opportunities for more direct integration of the physical world into computer-based systems, resulting in greater efficiency, economic benefit and reduced human exertion.

It is estimated that as of now, seven billion devices were connected to the Internet as part of IoT, and that this is likely to increase to about 30 billion by 2020. More and more applications are being developed under IoT, covering fields like infrastructure, manufacturing, agriculture, energy management, environmental monitoring, building and home automation, metropolitan scale deployments, medical and healthcare, elder care, transportation, etc. Facilities like monitoring our home online through close circuit TV, which is connected to the Internet remotely sitting thousands of kilometers away, switching on air conditioners and other devices remotely before reaching home, switching motor to lift water when a person is away from home etc., have become very common. As more and more devices get connected through the Internet, it will lead to the creation of a large number of jobs with diversified skills required for designing, manufacturing, marketing, distributing and maintaining these devices.

2.15 Block Chain Technology

Block chain broadly speaking means a network of databases spread across multiple entities which are kept in sync, where there is no single owner or controller of databases. Databases tend to append only, i.e., data items can be written to and cannot be altered without a broad agreement from participants of the network. This implies that a user or system administrator in one entity cannot alter data held on a block chain without agreement from other participants. Two examples implemented successfully are worth mentioning namely (a) Bitcoin and (b) the Japan Exchange Group Trial.

The concept of crypto currency can in fact be considered as the discoverer of block chain technology and perhaps the most 'successful' application of technology. An important difference between the bitcoin-network and most conventional networks is their topology in an organisation. For example, a typically conventional network is a university network, where the client wants to interact with another computer on the same network or a computer on a different network, when interaction is through the server. Online banking is another similar example.

On the other hand, the Bitcoin network is a peer-to-peer network. All nodes on the network are peers with equal standing. There is no server which contains accepted data base and provides services to clients. Instead, in a peer-to-peer network, some or all nodes in the network maintain copies of the database. May be, not all the nodes are necessarily connected to all other nodes. The consensus algorithm used in the proof of concept used by the Japan Exchange Group is quite different than the protocol used by Bitcoin. It may vary as per interacting partners.

Generalisation of block chain usage: Some applications wherein ownership registrations are useful can be listed as follows:

1. Block chain for proprietary registry in a country could be both worthwhile and relatively very inexpensive (functional in Georgia state, USA).
2. Block chains have been suggested for use in securities transactions. For example:
   i. The NASDAQ has created a trial block chain for public offerings and securities (NASDAQ 2015).
   ii. Overstock.com has created a subsidiary that provides a trading platform using a block chain (Trading began in December 2016).
3. The purpose of using block chain is to ensure the cycle between agreement on the transaction and final settlement.
4. The major possible benefit of a block chain for ownership is a relatively

simple one, i.e., standardisation across firms; this could shorten the settlement time and lower costs substantially.

5. The block chain with its ability to provide an immutable record in standardised processes has the potential to substantially lower the cost of providing trade finance.
6. Block chain can also be used in multi-stage transactions which are a part of what is included as 'smart contracts' based on a block chain.
7. The list of possible uses of block chains is far from exhaustive (Swan 2015 and Raval 2016) and includes a variety of applications underway. Block chains could be used as records to establish distributed autonomous organisations.
8. Many implementations of block chains are proprietary and details are not in public domain. By the term block chain, it essentially means not only Bitcoin block chain but also any sequential data-base that has distributed copies at various locations with consensus reached in one way or another by various parties.

Some of the sectorial applications of block chain that we may see in the near future in India can be listed below:

2.15.1 Banking, Media, Telecom, Education, Travel and Hospitality, Healthcare and Life Sciences.

There is no reason to think that currently known protocols for reaching consensus include all possible protocols. It is likely that research into alternative mechanisms for reaching consensus will have high value. The major issue detrimental to the success in unlocking the potential of this technology will be the ability for entities to collaborate closely, whether the entities are commercial firms, financial institutions or companies. Moreover, the evidentiary value of a block chain in a court of law is unknown.

2.16 Nanotechnology

Over the decade after adopting the definition and long-term vision for nanotechnology, programmes around the world have achieved remarkable results in terms of scientific discoveries that span better understanding of the smallest living structures, uncovering behaviours and functions of matter on the nanoscale, and creating a library of nanostructured building blocks for devices and systems. Diversified research and development results include technological breakthroughs in such diverse fields as advanced materials, biomedicine, catalysis, electronics and pharmaceuticals and expansion into new fields such as energy resources and water filtration, agriculture and forestry and integration of nanotechnology with other emerging areas such as quantum information systems, neuro-morphic engineering, and synthetic and system nano-biology. New fields have emerged such as spintronics, plasmonics, metamaterials, and molecular nanosystems. 'Nanomanufacturing' is already under way and is a growing economic focus. Nanotechnology has come to encompass a rich infrastructure of multi-disciplinary professional communities, ultra-advanced instrumentation, user facilities, computing resources, formal and informal education assets and advocacy for nanotechnology-related societal benefit.

Many nanotechnology breakthroughs have begun to impact the marketplace: current values for nanotechnology-enabled products are estimated at about USD 91 billion in the United States and $254 billion worldwide. Current developments presage a burgeoning economic impact: trends suggest that the number of nanotechnology products and workers worldwide is doubling every three years and is expected to achieve a $3 trillion market and 6 million workers by 2020.

The nanotechnology industry is in its infancy in India although it appears to be emerging with companies like Dabur active in nano-drug delivery, Mahindra and Mahindra looking at nanomaterials for enhancing performance of automobiles, Tata Chemicals is researching nanopesticide delivery mechanisms and ICannano is developing paints and coatings by incorporating nanomaterials. There are a handful of companies in India that are engaged in research and product development on nanotechnology such as Cranes Software International Limited, Monad Nanotech, Velbionanotech, Innovations Unified Technologies, Qtech Nanosystems and Naga Nanotech India. Leading companies like Reliance, Tata Group and Mahindra and Mahindra are making investments in this emerging area. Cranes Software International Limited has research set up for MEMS and Nanotechnology at India's leading institutions like the Indian Institute of Science (IISc), Bangalore. Velbionanotech, ranked Asia's Top 100 Bio-Nanotechnology companies by Red Herring in 2005, is designing drugs for various diseases such as heart disease, kidney stones, AIDS, cancer, and cosmetic generic products. These drugs are assembled in nano-chips and as nano particles for delivery inside the human body.

Monad Nanotech is another company producing carbon nano materials (CNM) commercially, using low cost production technology developed at the Indian Institute of Technology (IIT) Bombay. Besides, its involvement in the synthesis of carbon nano materials, the company is also working on their futuristic applications. Monad Nanotech has been supplying many nano materials to research organisations in India. Besides conducting research and development and producing nano materials, Monad Nanotech has taken up the agency of Shenzhen Nanotech Port Co. Ltd., (NTP) China, for sales rights in India and Canada. Similarly, Monad has taken the agency of Meijo Nano Carbon, Nagoya, Japan, for world marketing rights for its products, excluding Japan. Innovations Unified Technologies conceptualised by a group of IIT Bombay alumnus having specialisation in nanotechnology, is working on various projectsto supply small and bulk quantities of MWNT/SWNT produced by its pilot plant in three different grades. Qtech Nanosystems is a 'technology incubation enterprise' focused on making products based on nanotechnology. It is engaged in product development and commercialisation for Nano-positioning stages for nanotechnology and other varied precision applications.

Technologies to watch out for in the years to come:

1. IoT software solutions will enable customer control and provide operational realities a boost coupled with innovations like specialised sensors, actuators supported by

protocol diversity and realisation support.

2. Intelligent agents focused on AI and cognitive technologies will understand user behavior, self-interpret user needs and take decisions on their behalf creating about 11 percent global job loss and 5 percent job avenue openings in benefiting industries.
3. Augmented reality (both AR and VR) will transition into blending physical and digital experiences in our lives and work.
4. Hybrid wireless technology gets everything connected by a virtual network infrastructure that globally connects to IoT and customer engagement platforms.
5. Edge computing is also an upcoming field that is sure to gain momentum based on current advancement in research within the next decade.
6. Quantum computing setting its slow foot on the technological gradient will be a reality that does the implacable.
7. Green vehicle technology, self-driven cars are seen on the onset of a giant technological leap in the near future by companies such as Tesla, Uber, Google, etc.
8. Precision farming aided by Robotics, sensors, GPS, data-analytics, and much more can even allow for customised plant care.
9. Deep learning, an extensive space in machine learning techno-sphere can deliver analytic wonders that aid AI in its growing strength.

As more and more organisations undertake the process of digital transformation to offer tech-enabled products or services, IT roles and skills are undergoing radical shifts, something already being observed. This will affect the tech job scenario as we move into the future. Some key jobs might be:

1. Cyber Security Analyst: With the high penetration of Internet, there is a proportional rise in the risk involved as well. Personal security will be at stake and cyber security experts will be in high demand. This individual will manage risk for organisations through use of relevant tools and techniques to gather vital end-point and network host data with the goal of identifying vulnerabilities.
2. Network Engineer: This role will encompass coordinating between cloud and traditional networking resources to make a business communicate efficiently.
3. They will need to know how to map technical network elements (e.g., a router, an edge device, a micro data centre) to a company's business needs.
4. Vulnerability Assessment Manager: The role of a penetration tester has matured. Today's pen tester does more than hack a server or use fancy security tools. He takes a responsible approach and conducts strong, comprehensive tests to identify and correct unacceptable risks.
5. Technical Support Specialist: Gone are the days when the help desk professionals fixed PCs. The world needs more tech support specialists

than ever before. Today's tech support engineer helps manage increasingly complex issues involving data management, authentication and network trouble-shooting.

6. Machine Learning Engineer: Machine learning uses sophisticated programming such as R and Python to develop AI machines and systems that can learn and apply knowledge to perform tasks. These professionals will also work with complex data sets and algorithms to convert machines into intelligent machines.

7. Network Analysts: Businesses are investing more heavily in their networks as IoT is fast becoming critical to manufacture tech-enabled products.

8. A growing number of 'things' need to be connected in an efficient way and that is going to be a major driver of demand there. Network analysts, in the coming years, will combine their technical skill sets with an understanding of how to apply the same to provide real-time trending information on network traffic, and what those insights mean for the business.

9. Cloud Engineer: Almost all businesses are mobbing their on-premises systems to cloud and are choosing a hybrid approach with multiple vendors. In the coming years, cloud engineers will need to create solutions which are mix of multiple technologies. Gone are days when an Amazon engineer only worked on AWS or Microsoft engineers only on Azure. With the growing needs of the customer and changing technology, engineers will need to adapt their knowledge, learning and skills to prepare for the future. Apparently, it appears that increasing automation and ICT and technological adaptation shall adversely affect the employment market. However, implementation and management and adaptation of high level emerging technologies shall surely require highly skilled experts in the field; and would also generate semi-skilled and unskilled jobs around it. Typically, the new job generation shall be in the ratio of 1:4:10 for highly skilled, semi-skilled and unskilled categories. There is no denying the fact that main component of the technology-driven project's cost shall be the machinery/tools/higher-end high precision infrastructure, its maintenance and regular upgradation, etc.

10. Good quality STEM Education is expected to generate a work-force not only for highly skilled R&D domains but to also provide skilled and semi-skilled manpower who can think independently and unskilled ones who can work with minimum human supervision. STEM education is also expected to significantly improve the man-machine interface.

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Chapter 7: Some More Suggestions

By education, I mean an all-round drawing of the best in child and man in body, mind and spirit.

– M.K. Gandhi

During the last six chapters, quite a few recommendations have been made in the context of the contents. No attempt is being made here to reproduce those recommendations or to consolidate all the recommendations made in various chapters. Just to remind, some very strong recommendations are made in the first four chapters on policy issues, promotion of STEM Education, creativity enhancement and computational thinking respectively. However, some significant suggestions which have a direct and strong bearing on creativity and STEM education but could not justifiably be confined to only one of the earlier chapters are explained below. It may also be observed that many of these recommendations appear to converge at the 'micro level' for establishing a better correlation between intrinsic capabilities, aspirations and industrial requirements.

1. Improving Science Culture in Education

As has been brought out earlier, our education system is not helping adequately in bringing out scientific temperament, without which STEM education is really not being appreciated. Some observations in this regard are:

1. Indian philosophy recognises two modes of acquiring knowledge, internal and external. A harmonious blend is recommended for greater insight and balanced living. **A holistic approach is essential**. The idea is not to reject or overthrow western science, but to assimilate and synthesise, to make science more effective, interesting, accessible and humane in the best traditions of Indian culture.
2. As a policy, there is a need of new and effective mechanisms that address how to leverage our ancient and cultural strengths, and integrate those with our present-day formal higher education system in a balanced manner. Merely changing history chapters in text books will not take us far. **A high level committee should be constituted to look into ways in which the six traditional Indian systems of philosophy may be taught at the school and undergraduate level. Introductory textbooks should be written to introduce the subject to young minds**. India's philosophical traditions are perhaps the most significant civilizational achievements and must be made known to future generations.

3. A good amount of flexibility in curriculum must be introduced. Of course, this goes along with commensurate accountability, and therefore ethical and credible evaluation systems should be worked out. The emphasis should be on increased student-teacher interaction and student participation in learning.
4. Incentives for teachers and educators in terms of working freedom should be evolved. Teaching, as a profession and career option should be encouraged and made more attractive, if not monetarily, then at least socially. National teaching awards at all levels should be made more visible and given prominence over similar awards like films and arts.
5. Fairly good physical infrastructure exists in various forms. One major problem in implementing these measures at the ground level is the insignificant number of faculty with the right mind-set. **Nation-wide teacher orientation programmes should be carried out, especially by science education institutes and bodies**.
6. It is absolutely imperative that the current situation of STEM education in India be considered as critical. **If 'out of the box' solutions are not found and implemented, we may as well consider the present as the beginning of an unstoppable degradation of academic, intellectual and creative atmosphere in the country**.

To prepare the next generation for better STEM preparedness, a few suggestions are:

Some of the brightest minds in the country can be found on the last benches of the classroom.

– A.P.J. Kalam

1. **During school education, an evaluation of natural inclinations of students should be carried out**. There is a mad rush for prestigious science courses which disregards inclinations. Students, parents and teachers should not think that good marks are an indication of natural inclination. If a proper evaluation is done at the school level, it will help reduce the number of students and offer a scope for redesigning courses at the undergraduate level. This evaluation should be continued at the undergraduate level as well.
2. **If our society can pick up aspiring musicians effectively, it should be possible to do so for scientists and technologists as well**. Our school teachers are perfectly capable of recognising particular talents in their students and this information should be used in the distribution of students to various streams instead of just relying on marks and cut-offs. We also need to respect and give space to other disciplines so that each of them can get their share of talent.
3. **Undergraduate teaching of science should include courses on history and philosophy of science**. Providing a philosophical basis of science will naturally establish links with the humanities and the other arts. It will also reinforce the creative nature of science. **We should also encourage**

students who display a natural tendency for these topics to pursue them at the higher level (doctoral) and ultimately become teachers of the same.

4. While emphasising and providing a philosophical basis to science, the achievements of ancient Indian philosophical traditions should certainly be included but one must avoid marking modern achievements of western science as the only accomplishments of our imagined past.
5. Education must place great emphasis on observation of nature.

The highest education is that which does not merely give us information, but makes our life in harmony with all existence.

– Rabindranath Tagore

Science was once known as natural philosophy and students must be trained first as naturalists, and only then as scientists and engineers. Observational projects must be introduced at the school and undergraduate level that require observation of natural phenomena and a recording of those observations. Equal weightage should be given to classroom learning and field observations. Careful observation of small, everyday phenomena would help students develop physical intuition, identify problems and to abstract. Hopefully, such projects may also turn into original research material later on.

1. Pictorial thinking should be developed by including essay type questions and answers. This was a practice earlier but was discontinued primarily for handling large numbers in a small time frame. Today, there is a great emphasis on objective type questions and answers. This results in a view of science that is fragmented and piecemeal. The true picture, the big picture, emerges only when a student is allowed to take time to read and write in detail, exploring connections. It is these connections that pave the way for greater understanding and innovative thinking.
2. We must introspect; we must formulate our own problems and questions and then try to find answers. We must identify crucial issues and hold nation-wide competitions to address those issues. These competitions should allow everyone to participate irrespective of their educational and professional background. Needless to say winners should be rewarded handsomely.
3. Research carried out in national institutions and laboratories should be made to look inwards. Application-oriented research should not be put on a different pedestal as compared to the so called 'pure research' which may appear to have no immediate application.
4. Pure research, on the other hand, should be made accountable for a) following problems consistently over a period of time; b) starting and maintaining school(s) of thoughts; c) taking an intellectual stand on various scientific and philosophical issues (may be at variance with the trend), and last but not least; d) originality.

To rectify the situation, we need to take some concrete steps. The suggested journey for the first phase is:

1. To prepare a group of teachers to implement creative science and engineering teaching. This is the most important job, and to begin with, we can target about 100 teachers across the country (preferred age bracket 30–35 years).
2. To implement creative science and engineering teaching, with an emphasis on pedagogy and an evaluation system, without tinkering too much with the curriculum. To begin with, we may just choose 20 autonomous institutions in the country (10 each in science education and engineering education).
3. Although not a hard rule, our primary attention span could be on some select areas. (Suggest: 'Affordable Health Care' and 'Productive Agriculture and Farming').

On the successful completion of the first phase (which in itself is a challenge); scale up of the model appears easy, and the approach may help us considerably.

2. Introduction of B.Tech. (Vocational) on a Massive Scale

To appreciate this concept, the following observations may be made first:

1. B.Tech. remains one of the most popular courses for school graduates after Senior Secondary Examinations, particularly for those who study science with mathematics (popularly called PCM). The popularity of this course can be judged by the fact that the Joint Entrance Examination (JEE) remains one of those examinations in the world with highest rejection ratio.
2. In the last more than three decades, expansion of engineering education has majorly been in the private sector. This was particularly aimed at satisfying most admission seekers without making a dent in government resources.
3. Unfortunately, a very large percentage of colleges/universities offering B.Tech. Courses are producing graduates of unacceptable quality. The situation, though bad enough in several government institutions, is certainly worse in most private institutions (notwithstanding few of excellent quality). This has been confirmed by repeated surveys conducted by many agencies (NASSCOM, for example found just about 15 percent graduates employable).
4. While it is difficult to quantify the percentage of acceptable colleges, some of indicative parameters could be:
   i. Percentage of colleges which have scored more than 50 percent marks in the National Institute Ranking Framework (NIRF) – which is certainly less than two percent.
   ii. Percentage of engineering graduates who pass Graduate Aptitude Test in Engineering (GATE) Examination at the National level – which is certainly less than five percent.

iii. Percentage of engineering programmes accredited by the National Board of Accreditation with full accreditation – which is again less than five percent.

The situation is resulting in many paradoxes such as:

1. Very poor quality of most of B.Tech. Graduates.
2. Seats remaining vacant in most engineering colleges, thus disturbing their business model, resulting in cost cutting which in turn reduces quality still further, and this cascade effect continues for quite a few generations of graduates.
3. In a degree driven country like ours, seats being available in plenty in engineering colleges, the quality of students and the number of admissions in the diploma colleges keeps reducing further, thus depriving the country of good quality technicians.
4. Most of the students being admitted into B.Tech. programmes **do not have the intrinsic capacity to take on the rigour of the present level of curriculum**. They find it difficult to pass examinations – resulting in huge back logs and attendant problems.

To conclude, we are producing a very large number of quarter baked engineers (half will be too much of an overstatement).

To take care of the situation, it is suggested **we introduce another four-year engineering degree** programme, which may be **called B.Tech. (Vocational)** in addition to the current B.Tech. Programme. Incidentally, a similar practice by different names exists in several countries, the best examples being Australia and Germany. The special features of this new programme may be:

1. B.Tech. (Vocational) in any institution may be introduced in most of the existing disciplines in which a B.Tech. programme is currently being offered. For example, B.Tech. (Voc)-Mech Engg., B.Tech. (Voc)-Computer Engg., and so on.
2. The curriculum for these four-year B.Tech (Vocational) programmes be so designed that **there is a clear cut dominance of skill-based courses**, thus giving these students an edge for maintenance/production jobs as compared to design or research jobs. Also, there will be several project courses and internship courses in B.Tech. (Vocational).
3. AICTE-approved colleges may be permitted to opt for B.Tech. (Vocational) courses in all disciplines where B.Tech. has already been approved. The colleges may exercise this option in place of, or in addition to B.Tech. programmes.
4. **Admission norms to B.Tech. may be made restrictive**, such as fixing minimum marks at the Senior Secondary level (say 60 percent) or a minimum performance in JEE (say rank better than two lakh). Other students of engineering will have to be admitted to B.Tech. (Vocational) only.
5. There should, however, be an enabling provision for horizontal mobility between two courses in the first two

years, for which detailed guidelines will have to be worked out.

6. Approval norms and accreditation norms for B.Tech. (Vocational) will be suitably devised by the AICTE and the NBA respectively.

Ultimately, we might expect a much larger output of B.Tech. (Vocational) graduates than B.Tech. graduates, but they will be better skilled for routine engineering jobs. This step **will bring out compatibility between attained levels in engineering colleges and meet the requirements of most industries** in the country.

3. Aligning Engineering Education with the Economy and Society of the Region

Given here are some specific ways in which these goals can be met, keeping in mind the challenges and issues that would need to be addressed.

Linking the programme with the economy and industrial communities of the region:

1, A detailed survey would be done of material resources, industrial products, processes, implements, tools, technologies, knowledge, skills, etc., available within the region that determine income levels, employment and economy of that region. This survey would cover all major activities like agriculture, gardening, animal husbandry, textiles, crafts, tool making, building construction and repair, water and forest management, food and agro-processing, healthcare and medicine, electronics, communication, computers, IT, media, music, entertainment, cultural activities, etc**. A comprehensive GIS-supported profile of the region and its people would be developed and used extensively in the programme.**

2. In coordination with relevant agencies and organisations, the institution would set up a comprehensive exhibition/workshop in their campus pertaining to the above industrial base of their region – using working models, lab scale models, demonstrations, pictures, animations, charts, videos etc. This exhibition would be the central location for much of the practical aspects of learning during the entire B. Tech. Programme, as well as for research and development activities.

3. Multi-disciplinary teams of experienced persons (academics, engineers, economists, planners, industrialists, administrators, sociologists, etc.) would examine data gathered about the region (step-i above) and suggest ways by which regulations, curricula and syllabi of the B. Tech Programme could be drawn up so that education could (i) absorb from; and (ii) contribute to; the functioning industrial base of the region. The draft curriculum drawn up by these experts would be presented to artisans, craftsmen, industrialists, businessmen, government departments, NGOs etc., of the region to get their reactions and responses and then incorporated into it.

4. **The curriculum would expose students to the history, culture, industry and economy of the region**

so that their education can have a significant and direct connection with the area, though much of what they learn in the programme would be valid even beyond.

5. As far as possible, practical, workshops, projects, internships etc., would be **directly linked to ongoing industrial and economic processes of the region** so that by the time they finish their course, they have an excellent understanding of the region. Projects and R&D problems would be drawn up based on the real life context of the region, and the solutions developed would be fielded back into the region.

6. Craftsmen, skilled workers, industrialists, businessmen, managers, etc., from the region would play the role of advisers, faculty, guides, experts, etc., within a suitable regulatory framework that is drawn up for the programme. All such personnel would be suitably compensated for their inputs.

4. Linking the Programme with Organised Industry (Large and Medium) of the Region

1. **Industry will be closely associated with the curriculum and syllabi-making process** so that engineering manpower requirements of the region would be suitably reflected.

2. They will be encouraged to contribute to the instructional and mentoring process, especially on the applied and practical aspects of what the students are taught and how they are examined. They will guide and assist in internships, projects, etc., that the students take up.

3. They would be encouraged to build close linkages with the institution for their requirements of manpower, skill development and up gradation, R&D support, etc., thus making their **relationship with the institution a two-way process with both parties gaining from it**.

4. The above steps would be facilitated considerably by the industry setting up their physical presence in these campuses through stalls or concept centres to give the university community a close look at their activities, as well as getting themselves some visibility in the academic and R&D community.

5. Expectations from the Programme

1. By the time they pass out, the graduates would be capable of identifying and understanding real life engineering problems in the context of their region (and other similar regions elsewhere) and finding solutions that can be deployed in practice.

2. Through their interactions and involvement with industrial and artisanal practices during studies, they would have developed a good understanding of the industrial and economic processes of the region so that they would be able to contribute significantly to the same.

3. Those **who have entrepreneurial inclinations would be equipped to**

start technology-based businesses, primarily based on the material and human resources of the region (or similar other regions elsewhere) and catering largely to the needs of its people, especially jobs.

4. R&D activities would be centred on finding solutions to industrial and economic problems of the region and its people, especially artisans, craftsmen and retailers. The locality and region would serve as a primary source of research and solutions to problems, if any.
5. The goal of the proposed programme would be to see that at least 75 percent of the class finds a professional calling within a year of passing out – typically one-third going into entrepreneurship (self-employed), one-third becoming employees in the industry of the region, and one-third joining software / IT corporate companies or higher studies.
6. Students need not stay back in their own localities if they do not wish to and can move to other areas in the state or country since overall conditions of industry and economy might not be too different.
7. While the local and practical would be emphasised in the curriculum and syllabi to achieve the above goals, adequate exposure would be given to the global and theoretical to equip graduates to take up higher studies or careers abroad. This would be the challenge that curriculum designers would have to meet.
8. **Testing, evaluation and grading of the student performance would be done quite differently** from conventional programmes. In fact, the appropriate method of doing this in a manner acceptable to universities and potential employers would be a major challenge.

6. Experimental Introduction of B.Tech. (Integrated Engineering)

In engineering education, undergraduates are admitted to one of the specialised branches such as aerospace, automobile, biotech, chemical, civil, computers, communication, electrical, electronics, mechanical, etc. In a typical four-year undergraduate engineering curriculum today, the first year is normally devoted to subjects like mathematics, physics, chemistry, English, computer programming and drawing, taking up about 25 percent of the total credits. Providing for some courses in management, economics, etc., the balance 70 percent of the credits (coming typically to about 30 papers or subjects of study) for the undergraduate programme are devoted to subjects in the area of specialisation. While there may be some flexibility available in elite engineering institutions like the IITs, this structure is pretty much what 90 percent or more of our engineering graduates go through.

The assumption behind this structure seems to be that the employers are typically large corporations or government departments who would be wanting adequate number of engineers of various streams for their work. For example, the railways would hire engineers with specialisations in civil, mechanical, electrical, electronics, computers, communication, etc. The mechanical engineer in the Railways would not be required to know any communication engineering, as the Railways have specialised communication engineers with them. The Indian Space Research Organisation (ISRO) would not need their communication engineers to know anything about structural engineering since they would have hired separate engineers for that purpose, etc. Same is the case with large corporations like Reliance Petrochemicals, Tata Steel etc. For such an employer profile, the present scheme of undergraduate engineering education with specialisation in different disciplines does make sense, coupled with reasonable revision of syllabi periodically.

The environment in which engineers have to work and the demands made on them in the MSME/Startup sectors are often very different from what their counterparts face in large enterprises. Here, a handful of them (at times just one) would be required to attend to the different engineering needs of the organisation, going well beyond their own specialisation. An engineer in a small company cannot say 'I am only an electronics engineer and cannot be expected to know anything about chemical dyes' etc. An engineer possessing reasonable knowledge of all trades becomes critical for the survival of small industrial units, especially in their early stages.

Our undergraduate engineering degree programmes don't address such a context and this is not a gap that can be addressed by a few weeks of orientation or pre-induction training programmes. Engineering graduates need to have different mindsets and self-perception, besides technological preparedness in order to address this shortcoming.

Another reason why it is necessary to impart in-depth knowledge (amounting to doing around 30 papers) in a chosen stream is perhaps the fact that until recently, all learning had to happen either in college or at the work place. This is no more the case, thanks largely to the spread of Information and Communication Technologies (ICT) and online learning environments. A lot of learning in any field can happen today outside of these two locations, especially if the learner is exposed to basic principles and concepts within the disciplined structure of a classroom setting earlier. To illustrate, if one has done five to six carefully designed papers in chemical engineering at the undergraduate level, then he/she should be able to build on that through a process of web-based learning to meet all needs of this particular stream in a medium-sized electronics industry, etc.

The need today is for 'Integrated Engineering' to meet the demands of the 'non-formal/un-organised' sector industries. What is needed is a new undergraduate engineering degree called 'B.E. (Integrated Engineering)' for which curricula would have to be created. It would continue to be a four-year programme with about 25 percent credits (10-12 papers) devoted to English, maths, physics, chemistry, biology and computers, as it exists now. The remaining 75 percent credits would be distributed nearly equally amongst four to five engineering disciplines,, say chemical, civil, communication, computers, electrical, electronics, materials and mechanical engineering, in addition to some exposure to management, marketing and finances. A student may be attempting five to six papers in each of his or her chosen areas, with some specialisation in a selected branch made possible through electives, projects, internships, etc.

Such a programme would have to be designed from scratch and not simply be assembled with the help of a few existing papers from existing engineering streams. Also the candidate would have to be clearly informed about the difference between this programme and other existing programmes, as also the targeted main employment sector. **On a lighter side, considering that most engineering graduates end up in the IT/SW industry, the B.Tech. (Integrated Engineering) programme may in fact be a better fit there!**

While the engineering education fraternity might disapprove of what looks like sacrificing depth for breadth, it helps to note that there is no specialisation at the undergraduate level even now in other major professional fields like medicine, law etc. The first level degree programmes in these fields are entirely broad-based that everyone must go through, with all specialisations left for the postgraduate-level programmes. There may be some lessons in this for us in the engineering field.

Also, there is the possibility that the strong cross-disciplinary exposure that a student receives right from the beginning may in fact spur innovation and creativity in them. Incidentally, a similar proposal is doing the rounds in the United States with the title, B.Tech. (Seamless Engineering).

7. Enhancing Skill-levels into the Formal Education System

There has been a persistent paradox as to how to translate very large (but also very essential) requirement of skills in a sustainable way within the educational and cultural fabric of the nation. Basically, the experience of about four decades in the country's higher professional education system, culminating in the establishment of Indraprastha University in Delhi as its founder Vice Chancellor, has helped the author to illustrate the following concepts on this widest possible canvas of professional education:

1. **Dispelling the prevalent myth that 'Hands-On' does not gel with knowledge creation** which is rightly (but not exclusively) the core concept of universities.
2. The involvement of industries and professional societies is very useful for designing employment-oriented courses.
3. While universities may not design 'employment and placement' as their primary focus, they must not shy away from allocating resources (manpower as well as monetary) to facilitate the same.
4. Entrepreneurship is a **MUST**. It is a requirement for leading the change wherever one is employed.
5. **Entrepreneurship, innovation, creativity, wealth and knowledge generation cannot be treated as separate entities as they are highly interwoven.**

8. Some Observations, Based on the Author's Experience

1. Ours is still a degree-driven country. Parents and students do wish to have a university degree in their hands to keep both options open i.e., for employment (formal/non-formal/self)

and higher studies. This is likely to remain for some time till we are able to provide social respectability to skilled professionals.

2. Vocational content in higher education has not really take off, as the 'Mix and Match' phenomenon has not been in keeping with what the student wishes.
3. There is a perceptible but not always desirable shift from general education to professional education. The growth of professional education is imperative and has to be speeded up still more, but general education must not be ignored.
4. The cost of higher professional education in the country (which is mostly in the private domain now) has normalised with reference to per capita GDP. In several situations, the determining factor is not the unit cost, but the paying capacity for good employability.
5. All institutes need to be sensitised to inculcate creativity among the STEM students, researchers and faculty too. They may be offered support by way of incubation centres, research barracks, mentoring, easy funding, infrastructure support, etc. They may also be linked-up with the business schools for marketing and project management related mentoring.
6. In the last couple of decades quite a number of young researchers studied/ worked abroad but could not adjust with the local ecosystem on their return to India, and left for foreign shores again – some of them were associated with high technology, others were with power science – risks being different. . This warrants urgent attention and appropriate corrective measures to achieve an appropriate research ecosystem.

In this scenario of more relevant (or at times, just more fashionable) courses, our most common university programmes, B.A./B.Sc./B.Com. are almost out of sight. Some of the very significant features of these programmes are:

1. Maximum availability in the country – all states and all universities/colleges.
2. Also available in smaller towns, remote areas, backward areas, etc.
3. Still having the largest enrollment in higher education, available to all students.
4. In most cases, the fee is reasonable and affordable.
5. Probably, the widest selection of courses (way ahead of the present day concepts of menu driven or cafeteria-based approach). In general, a Bachelor of Arts student can choose any three subjects in addition to language courses. In several cases, the three subjects chosen may not have any correlation.
6. In this programme, we have learnt (though without formalism) that for a graduate, the quantum of effort put in and the achieved level in each course studied, is important. Measurement of academic maturity level is emphasised rather than knowledge level of most compulsory subjects alone. This is a great ground for self-learning attitude.

For example, a graduate with any combination of subjects is eligible for an entry level post in almost all government/ semi-government offices as also the right to sit for the most prestigious Union Civil Service Examination. We never really bother to correlate the courses studied with duties to be performed. Very rarely is a particular course studied which may be of direct relevance to his duties, but unfortunate that is the design. In this programme, **we have built in the concept that if you have learnt something well, you will be able to learn some other thing equally well.**

With this background in mind, the suggestion being made is to add several skill-based courses to the vast list of available courses in universities. The advantages could be:

- The student still acquires a graduate degree, which was his aim. He has not foreclosed any of his existing options.
- He can assess himself for his level of skill acquired and decide whether he can be an entrepreneur, or practice a skill, or go for higher studies, or an academic career, etc.

The following is, therefore, proposed here:

1. To draw a list of such skill-based courses which can possibly be added to the list of available courses in any traditional university? An illustrative list (which obviously needs considerable expansion) is:

   i. Office Management
   ii. Secretariat Practice
   iii. Traffic Policing
   iv. Vehicle Maintenance
   v. Electrical Wiring
   vi. Instrument Mechanic
   vii. Tourist Guide
   viii. Laboratory Testing (Pathology)
   ix. Construction Technology1
   x. Physiotherapy Assistant
   xi. Spa and Cosmetology
   xii. Security Management

2. To design the syllabi for such courses, keeping in view comparable efforts vis-à-vis existing courses.
3. At times, a combination of a traditional course and a skill-based course may be an extremely useful synergistic combination. Some such possibilities (again, many more combinations are feasible) are:

   i. History and Tourist Guide
   ii. Geography and Tourist Guide
   iii. Economics and Banking
   iv. Physics and Television Repair
   v. Physics and Hardware Maintenance
   vi. Psychology and Traffic Management
   vii. Commerce and Entrepreneurship
   viii. Commerce and Accountancy
   ix. Chemistry and Pharmaceutics
   x. Biology and Pathology

9. Academic Leadership

Education and religion are time-tested tools to bring in social transformation. The former is based on scientific logic, while the latter extends beyond logic and can be stretched to extreme limits of faith. Education has the power to overcome the latter by way of creating a culture of critical and rational thinking and a 'scientific temper'. This is exactly one of the main objectives of STEM education.

The present system of higher education has served our post-independence generation well, by way of an established knowledge-delivering system. **The emphasis so far had been on accessibility rather than on quality, knowledge creation, invention and innovation**. The time has come to start working on mechanisms that generate high quality educators, scientists, engineers and researchers capable of knowledge creation, entrepreneurship, handling live problems, local needs and global compulsions.

There are certain institutions of higher learning which hold unique core values that define the institution in a positive manner in the minds and hearts of its members and associated stakeholders. Some of these values and characteristics, peculiar to any institution of higher education are:

1. Knowledge and expertise is the basis for respect and status;
2. A general tendency towards moral superiority;
3. A heightened sensitivity to individual rights;
4. The necessity for autonomy to pursue and transmit knowledge;
5. A belief in the institution as being an idea generating platform;
6. Self-discipline and a reflective solitude.

The above characteristics **necessitate academic leadership to go beyond conventional** qualities. It is often commented on for its absence, sought out, but carefully 'watched' when it is present and never to be acclaimed as a personal ambition. It permeates the institution. While an accepted definition or notion of leadership might be elusive, the academic community recognises leadership when it sees it. It is said that no one dreams of a career as an academic administrator. It is a tough job that gets more challenging as budgets shrink, public scrutiny rises and responsibilities grow.

Fundamental changes like increased awareness of a democratic approach to decision making, globalisation, regionalism, caste-based polarisation, and above all, the extreme pace of technology-driven developments are transforming societies. This transformation, while important and necessary, is very often painfully difficult for people and institutions. These changes produce several problems that require time, attention and often a significant change in the behavior of the university community, and therefore, a very different type of leadership quality. Problems arising from issues of size, diversity, quality, technology, resources and multifaceted roles are interrelated and not easily addressed. **Academic leadership is changing constantly and fast.**

Most persons assuming leadership responsibilities are highly knowledgeable and skilled in their own discipline but talented amateurs in leadership and management. Most have learned 'on the job', chairing departmental and senate committees, and holding other administrative responsibilities at the level of Dean and/or Director. While learning on the job (apprenticeship model) plays an important role in contributing to the general preparedness of an individual to assume an administrative post that carries expectations for leadership, it is not enough. The current, complex and often contradictory expectations and demands of peers, the institution and society require that academic administrators possess a more in-depth and broader knowledge base than is provided by learning on the job.

9.1 Attributes of Academic Leadership

While leaders may look and think differently, it is likely they share the following attributes:

1. Vision (the ability to communicate to others what a destination may look like and be like and instill motivation in others to move towards that destination).
2. Voice (the ability to listen to what is said and not said by members of the group and to express those wants, needs, hopes and fears to others).
3. Credibility (the ability to do what one commits to do).
4. Commitment to action (a sustained focus over time is often very difficult and depends on circumstances).

The likelihood that a particular person will have these leadership attributes depends in large measure on who they are and the environment in which they have been raised and have worked. The degree to which each of these attributes has been developed depends on the person's life experiences, including cultural norms, values, education, training, personality, work experience and access to power. Leadership can and does occur in domains of teaching, research and academic administration.

- *Teachers* define who will be taught, what and how it will be taught and set the standards of evaluation on what has been learned. *Leaders in teaching* are imbued with an extraordinary ability to know what knowledge is more critical to teach, excite students and peers about learning, know which teaching practices are most effective and invest their considerable energies in the promotion of student learning.
- *Researchers* define questions and seek answers. *Leaders in research* have the ability to identify and answer particularly important questions, seek connectivity and are driven to communicate their work to others.
- *Administrative leadership* is the force that drives the institution as a whole. Administrative positions at the senior level are vested with responsibility, whether derived by statute, charter or articles of incorporation, for ensuring that the institution and its members fulfill their educational, social and ethical mandates. *Administrative leaders* may or may not be leaders in either teaching or research, but it is expected that they are respected for their judgement, institutional knowledge and predictive powers. Such individuals are usually drawn into the institutional structure through appointment to senior administrative posts.

Any person so appointed at the top position of an institution of higher learning is expected to encapsulate all the above characteristics in one place. Defining the characteristics is rather easier than identifying and nurturing personalities that possess such qualities. Unless this is done, there is little hope of improving the educational standards and management efficiency of our institutions of higher learning.

In the present system, appointing the head of institutions has very often been manipulated to such an extent that at times it no longer results in the appointment of competent persons as academic and or administrative heads. It is imperative that such selection should be done on pure academic competence and professional credibility.

9.2 Ensuring Academic Leadership

Accountability at the level of leadership is a sensitive but important issue. By virtue of the position itself, being in the public-eye, it is desirable to have in place some robust mechanisms to ascertain impact of leadership qualities.

The overall growth of an institution may be measured in in terms of (i) national and international ranking, third party accreditations; (ii) proactive academic and intellectual activities and outcomes beyond normal functioning like classroom teaching and evaluations; (iii) realistic feedbacks from various stakeholders; and (iv) the quality of the out products, both in terms of student training and in terms of other tangible outcomes like research, inventions and knowledge creation. Some more recommendations can be:

1. In the formal sector, the idea/proposal for the establishment of an Indian Education Service is welcome. This can generate a quality workforce of educators and scientists with a sharp national perceptive. They can be nurtured to grow as a national pool of academic leaders for the future.
2. In the informal sector, nation must identify around 5,000-10,000 ethical and visionary educators/leaders of credible stature who have at least:
   i. some vision and a long-term perspective;
   ii. have done quality research work at some stage of their career;
   iii. are familiar with and sensitive to ground realities;
   iv. are capable of decision making;
   v. are capable of team building; and
   vi. have a capacity to lead from the front.
3. To develop, recruit and retain a pool of around one lakh excellent quality STEM teachers over the next 10 years.
4. To develop a quality assurance mechanism for higher education that is *easily implementable, operationally feasible and has a large measure of credibility and acceptability.*
5. The above framework has to not only be in line with local needs and national requirements, but also live up to best international practices, particularly in the context of freedom and accountability.

10. Quality Teachers for STEM Education

The quality of the out product, i.e., students, is directly proportional to the quality of teachers and researchers involved in processing, delivering, disseminating and

creating knowledge. So far, in our system, teachers are treated like 'employees on a hiring basis'. It is such a sharp contrast to the '*guru-shishyaa paramparaa*', wherein, the teacher-pupil were treated as one unit.

1. At present, a Ph.D. degree is virtually perceived to be a necessity for teachers in higher education institutions. However, it may not be an absolute necessity for every teaching position in every kind of college/institution. A large percentage of low quality Ph.D. degrees are being handed out due to the pressure of necessity for acquiring the degree. This is quite detrimental to national interest.
2. **Mechanisms for ensuring that they stay motivated and updated is essential:** such mechanisms may not be in their quality of research outputs. Rather, appropriate promotional avenues and defining and well-meaning job satisfaction levels to ensure loyalty, attachment and commitment to the institution.
3. Over the past decade, frequent changes in recruitment qualifications/ eligibilities have led to poor quality research, particularly at the Ph.D. level by those interested in only getting jobs.
4. Time-bound promotion schemes and the way they have been implemented has considerably diminished the quality of the output at the post-doctoral level (early stages of research career).
5. The latest API system has led to very low quality research publications, wherein the sole intention (the way national conferences and seminars are organised) is to enhance their API score.
6. mushrooming of so-called peer reviewed journals which are ready to accept and publish practically every paper received (many times on payment basis) is a highly distressing phenomena).
7. These developments have **seriously damaged the zeal of serious and original research** initiative among younger faculty.
8. In the past decade, India's overall share of research publications in the world has risen from 2.8 to only 3.4 percent – a very small incremental improvement. Despite a few pockets of excellence, the system is marked by mediocrity.

We have to promote multi-disciplinary research and promote research groups rather than individual research in a narrow subject area. Even Masters and Doctoral research in science and engineering are theoretical and rarely inter-disciplinary. Engineering and medical-combined research can bring lot of innovation. Computing and programming combined with sensors and electronics have tremendous scope in medical science. Similarly, **almost all other science and engineering disciplines research can be augmented through researchers from computer science**. Hence, there is a need to establish computer science departments in two different directions: Core Computer Science (CS) and Applied CS. Applied CS faculty and students must support and collaborate with other disciplines and all prominent National Technical Institutions need to have a strong applied CS department.

Most publications resulting out of research at the Masters and Doctoral level are theoretical and for the sake of publication only. Simulators and simulation works are mostly the basis of research and results. A policy needs to be made that motivates and inspires both students and faculty to do research such that the product or at least a prototype is developed. The evaluation should also focus on product orientation and it should be ensured that innovative ideas are awarded better grades and suitably acknowledged and rewarded.

Schemes like the Prime Minister's Research Fellowship (PMRF) scheme can become more successful if a provision is included that those who complete the Ph.D. through the PMRF will be appointed in NIT/IIT as faculty or as scientists in research organisations. This decision should be on the basis of interest and research outcome. Making the Ph.D. compulsory, without adequate preparation at the national-level has not delivered good results. Generally (except exceptional candidates), below average students of B.Tech. go for M.Tech., again only average students of M.Tech. go for Ph.D. A good student of B.Tech. from an IIT/NIT is not coming forward for teaching or research as he does not wish to wait for six to seven years to complete his Ph.D. to start his career. So, **early induction programmes need to be revised and reintroduced after being made more effective and realistic**.

We need to develop, recruit and retain one lakh excellent quality STEM teachers over the next 10 years to enable us to generate a workforce of an additional one million students with STEM majors. We also need to concentrate on improving delivery, impact and feasibility of STEM efforts.

11. Hand-Holding of Private Institutions

It is an established fact that many more engineering graduates are being produced by private colleges or universities as compared to government-run institutions. Most don't meet the expectations of the country's industry and society requirements. This is a serious situation that cannot be limited to criticising the private system. **We have to raise the standards of these institutions to acceptable levels**. Asking them to compete with the best in the country is impractical, although it is worth reiterating that a few of them might eventually compete or even outperform the best of today. A few suggestions are:

1. There must be some teachers (at least one per department) selected, appointed and then deputed by the affiliating university to private engineering colleges and by the respective government in case of private universities. These teachers will be transferrable.
2. **These teachers will serve as onsite checks on such institutions, which appears to be a necessity**.
3. To meet the expenditure of these appointments, part of the fee collected by these colleges or universities will have to be remitted to the university or the government, as the case may be.
4. The universities giving Ph.D. degrees in engineering will have to be monitored very carefully. The **sub-standard award of Ph.D. degree leads to the appointment of sub-standard senior faculty**. Once that happens, to arrest the decline is practically impossible.

5. Once standards are met, all expenses on doctoral research can be met by government as a national human resource investment. In this absence, colleges and universities are not spending enough on research in engineering, which is essentially a cost-intensive proposal. Even if they do incur this expenditure notionally, it is at the cost of teaching for regular B.Tech./M.Tech. courses, which again is not in national interest.

12. Attention to Anomalies/Dichotomies

In this section, some anomalies/ dichotomies are briefly mentioned that deserve our attention for the long-term enhancement of the quality of education, particularly STEM education.

1. We do understand that inter-disciplinary exposure is necessary for creativity and essential for result-oriented STEM education. In general, the university system is more diversified, having a number of apparently unrelated faculties/schools. Also, as brought out in an earlier chapter, good quality STEM education is not only essential for science and engineering education, but for all forms of education to ensure more productive output by citizens.

2. It is painful to note that **most state public universities remain poor performers**. They need attention as more than 80 percent of students study in them. For any real demographic advantage, this is absolutely necessary. It becomes even more relevant in the wake of the Prime Minister's considered position on the need for promoting cooperative federalism. We must hand-hold states for more meaningful impact.

3. While we can be proud of some of our discipline-focused institutions, it is the university system that can ultimately provide us with inter-disciplinary solutions to the problems. As universities give attention to several subjects concurrently, their involvement at the highest level of quality will be needed for the country to rise to the expectations of our youth. We are, therefore, not surprised as to why we are lacking in quality in general and in inter-disciplinary subjects in particular. **To be proud of some of our institutions should not make us complacent.** Unless the average quality of the graduates rises, as a nation we will continue to have sleepless nights, or if we sleep, we will dream about what can be done about it.

4. **We already have various kinds of universities**, such as Central Universities, State Universities, Deemed Universities, Private Universities, Degree Awarding Institutions, etc. **Each of them are different (at least perceived different) in terms of quality.** Now, we are even adding a super class by the name 'World Class Universities'. In technical education, categorisation is even more marked: Indian Institutes of Technology, National Institutes of Technology, Government Engineering Colleges, Private Engineering Colleges, etc. It does not appear feasible to do away with this categorisation. Trends are similar the world over. In

the United States, for example, we have Ivy League Universities, state universities, private universities and community colleges. All have different roles, perceptions and quality metrics. In this context, **we shall have to design quality metrics in such a way that all these can serve their intended purpose**.

5. Institutions offering courses in professional subjects such as medical, engineering, architecture, travel and tourism, and hotel management have been promoted at different levels, as it is assumed that these sectors provide employment and are key elements of wealth generation. Let us not forget that other areas of education still take care of about 85 percent enrollment of undergraduate students, and out of these, over 80 percent study in affiliated colleges. There is an urgent need for improving under graduate higher education and STEM education.

6. It has been observed that there is too much stress on students, particularly in 11th and 12th classes. An unfortunate trend that has been observed is that most students taking up coaching in science subjects practically do not attend formal schools. The Board's weightage is zero again in JEE Mains. Students consider it impossible to crack the **JEE Advanced without coaching**. Coaching for the Mains and Advanced teaches certain tricks and shortcuts to solve standard problems and students become habitual of that. After coming to engineering, their approach to problem solving remains same. This needs to be stopped and the role of coaching institutes needs to be mitigated, if not eliminated. Nowadays, such coaching classes are starting not just from the 11th class, but from the 9th class and this ongoing trend is set to start from 6th/7th class. **Such early coaching stops a child's natural thinking process and development**.

7. At engineering college level, the quality of teaching has taken a turn for the worse, notwithstanding a few exceptions. Engineering education needs to be planned in a hierarchical manner. Institutes like IISc, IITs should focus on research and creativity. They can be made as postgraduate institutes primarily and offer M.Tech. and Ph.D.s only. They will get their students mostly from NITs, IIITs etc. NITs, IIITs and similar central institutes which can be middle-level institutes who offer mainly a B.Tech. programme and focus on producing quality engineers who either go to the IITs or go for the best product design/entrepreneurs. Then come the state-level colleges and private institutions whose focus should be to produce more engineers for average engineering jobs in the country. The IIT education system should focus only on innovation and research and they should produce quality technocrats who work primarily at the research and development level in the country. NITs etc., will produce good quality B.Tech. degree holders who are good in design and development. Some pass-outs of NITs will go to the IITs, some will become entrepreneurs

and some will take up engineering design and development. Third level institutes like state colleges etc., will produce B.Tech. engineers who are good in implementation and average level engineering jobs and their pass-out students will serve the engineering industry doing the routine and traditional engineering works. The faculty, resources and syllabi of IITs will be accordingly different from NITs, etc., and similarly for state-level institutes. Accordingly, the promotion rules of faculty should also be made different. Research component's importance in state-level institutes should be minimal and highest at the IIT level. The importance of teaching should be of a very high level in the state and in the NIT-level institutes.

8. Accreditation and ranking are potent tools to improve overall quality of higher education. If these are seen as end results with no takeaways, then it is really not serving any purpose. Higher education institutions find themselves in a quandary when they discover that many schemes and policies are incentivising only those that are ranked best. State universities and their colleges account for over 80 percent of the total enrollment in higher education. Sadly, it is these institutions that have taken a major brunt over a period of time as they were deprived of funding and faculty commensurate to the burden they share.

9. Looking at the list of ranked universities in the very first year, **Rank #2 has less than 75 percent of the marks of Rank #1**.

10. We have to generate competition to a level where this is not acceptable. In a large education system like India, there must be a significant number (at least 10 or so) to compete for the first rank, making it so difficult to choose. **Clustering at the bottom has to move up to clustering at the top. That is the only deliverable to increase the effectiveness of this exercise.**

13. Creative Awareness for STEM Education

We have to realise that **prosperity of countries** will not be measured by Rupees/ Dollars/Euros/ in the future, but **will be measured in terms of generated ideas**, which are implementable in the first instance. Some steps, which are expected to be helpful in this regard, are suggested below:

1. In an earlier section, we have advocated strongly for more flexibility in the choice of courses for B.A./B. Sc./B.Com. Here, we specifically talk about the B.Sc. course. Traditionally, our B.Sc. course has been a study of three science subjects with equal weightage, say A+B+C in the ratio of 2+2+2. Typically, A is Physics; B is Chemistry and C is either Mathematics or Biology. Thereafter, the graduate can go in for post-graduation in A/B/C. Then, some professional universities felt that the subjects for post-graduation are better decided during graduation itself and B.Sc. (Honours) was evolved with weightage to A+B+C as 4+1+1, whereby a student goes in for post-graduation in A. It is proposed that we can now go

in for several different permutations and combinations. There could be another variant of three years B.Sc. with four subjects having weightage as A+B+C+D as 2+2+1+1, thereby allowing students reasonably good knowledge of two subjects, which could be combinations like mathematics and computer science, physics and electronics, chemistry and biology, even mathematics and biology, etc. For students who would like to use the B.Sc. degree for another well-defined objective, say entrepreneurship, there could be a four-year B.Sc.(Hons.) course with four subjects A+B+C+D in the weightage of 3+3+1+1. This innovation may be worth a trial, but selectively.

2. Here, we mention some steps, which have already been initiated, but need to be up scaled, strengthened and incentivised much better as STEM education is in high demand with industries in today's highly competitive world. **We ought to create strong and conscious awareness that STEM is about the skills required to design processes through creativity, development of technology and discovery of need-based solutions**. Increasingly, global issues such as climate change, health, biodiversity, ecological sustainability and economic prosperity have forced policymakers to take serious steps to create an interest and motivate children towards STEM education.

3. Some steps that are certainly required to be up scaled are:

    i. National Children's Science Congress.

    ii. Innovation in Science Pursuit for Inspired Research (INSPIRE).

    iii. Science Express: A Mobile Science Exhibition.

    iv. Atal Tinkering Laboratories, ATLs.

    v. Science Exhibitions.

    vi. National Teachers Science Congress, NTSC.

    vii. Science Museums (An example: Indian genius on display in London).

    viii. TV or OTT channels (An Example: Vigyan Prasar).

    ix. Kits for STEM Education (FICCI and Martin Lockheed gave an award of Rs. 25 lakh to a college team a few months ago, to develop a kit for school level STEM Education).

    x. App Development: teaching STEM subjects in school.

Summary of Recommendations

S.No.	Recommendations	Proposed Action	Expected Time Frame	Remarks
1.	To increase GDP on education from 1 percent to 1.5 percent. Economics (analysis of cost and benefit) of higher education needs to be discussed in more detail.	*UGC: A* ***Standing Committee*** *for output-based financing mechanism for institutions of higher learning, suggest dynamic revenue models for private sector participation in higher education and research.*	*9-12 months*	**Game Changer**
2.	Expanding diversity in STEM education on national priority; noting that women and racial minorities are disproportionately under-represented particularly in the STEM-based private sector. Call for a focus on 'diversity, equity and inclusion' in STEM education; it needs to be made public friendly as private institutions are far behind in enrolling Scheduled Castes, Scheduled Tribes, Other Backward Classes and special category students in comparison to public universities.	*MHRD to workout modalities specific to and for STEM education.*	*3 months*	

S.No.	Recommendations	Proposed Action	Expected Time Frame	Remarks
3.	Need for holistic and innovative use of technology for teaching-learning and research. Integration of reformative schemes like SWAYAM to the larger teaching community. API (Academic Performance Indicators) or any other metric used to assess teachers in HEI should also consider their participation in MOOCs and SWAYAM platforms.	*MHRD to set up a high powered committee to work out modalities to sustain these schemes and its integration with the formal sector.*	*3 months*	
4.	Academic leadership 'must have' attributes: vision, voice, professional integrity, ethical credibility and output driven (with emphasis on quality, knowledge creation, inventions and innovations).	*VIF: 3-Member Committee to come out with concept document, including further line of action.*	*3 months*	Nation to identify 5,000-10,000 ethical visionary educators. **Game Changer**
5.	Professoriate temptations to seats of power in universities and research institutions to be dealt with – exceptionally good teachers and researchers to be adequately accommodated so as not to run after administrative posts.	*UGC to set up a three member Committee.* May involve ICSSR (Indian Council of Social Science Research)	*3 months*	
6.	Assessment and ranking methodology processes largely ignore 'process' variables and need to include indicators used by QS university rankings.	*NAAC to include components as discussed in the text.*	*3 months*	

S.No.	Recommendations	Proposed Action	Expected Time Frame	Remarks
7.	Professional development of teachers to address the issue of process of teaching-learning, including student assessment. Teachers ought to be dedicated researchers in a way as to involve unconventional thinkers apart from established experts.	*UGC + AICTE to set up a **Joint Cell** to develop the effective processes.*	*6-9 months*	
8.	Improving science culture in education by recognising science as a cultural and creative activity and allow time and space for growth of scientific temper. Bring a scientific temper to translate our strength of 'Jugad culture' into 'Culture of innovation'. Undergraduate teaching of science should include texts on history and philosophy of science to reinforce creative nature of science. Observational projects must be introduced at school and at undergraduate level that require observation of natural phenomena, and recording and analysing those observations. Comparable weightage to field observations and classroom learning is desirable and the habit of pictorial thinking is to be developed.	*MHRD to set up a national level cell with representatives from ICSSR and Ministry of Cultural Affairs to prepare the roadmap.*	*1 year*	**Game Changer**

S.No.	Recommendations	Proposed Action	Expected Time Frame	Remarks
9.	Suggest implementable strategies wherein traditional Indian systems of philosophy may be introduced at school and at undergraduate levels appropriately. Introductory textbooks should be developed to introduce the subject to the young minds. Indian philosophy recognises two modes of acquiring knowledge, the internal and the external, a harmonious blend is recommended for greater insight and balanced living.	***VIF: A high-level task force be constituted*** *to come out with a Concept Document (feasible models having foundations in our own philosophical and cultural strengths, and its integration with the existing formal as well as informal educational set up and develop linkages with modern research areas and fields).*	*1 year*	May involve a few *credible NGOs* and organisations like Centre for Policy Studies, Chennai **Game Changer**
10.	Develop a culture to understand and appreciate that creativity is an important part of being. Let us start gradually bringing in a culture of creativity to replace conformance. Training should lead to asking of questions, not just answering them, encouraging multiple solutions and bringing in a concept of divergent thinking.	***VIF: 3-member expert committee*** *to come out with relevant implementable suggestions.*	*6 months*	

S.No.	Recommendations	Proposed Action	Expected Time Frame	Remarks
11.	During school education, an evaluation of the natural inclination of pupils should be carried out. The solutions to STEM education cannot be just imported. We need an out-of-the-box approach, suiting our own conditions and resources. To enable this, philosophical basis of science in present day India has to be brought in and strengthened.	***High-powered committee*** *to work out modalities. MHRD with representatives from UGC, AICTE and ICSSR to develop flexibility and enough diversity in the existing formal and informal framework.*	*6 months*	
12.	• Recognise and work towards the fact that multiple intelligencies are to be inculcated in a child for the ultimate creative and productive society. Create an atmosphere hospitable to creativity. Develop methods to systematically identify creatively gifted children right from school to the profession. • Produce a scientific temperament which can develop creative and entrepreneurial knowledge. Appreciate that creativity in the classroom leads to creativity in the boardroom. Ensure creativity in engineering education as engineering is basically the creative application of scientific discipline. • There has to be a major component of **'computational thinking'** right from the school level till the higher education level.	*UGC & AICTE : Joint Committee: to work out modalities without too much tinkering of the existing curriculum.*	*Immediate*	First phase target 100 teachers and the second phase is to be aimed at selecting institutions – 10 each in science education and engineering education. **Game Changer**

S.No.	Recommendations	Proposed Action	Expected Time Frame	Remarks
13.	To prepare and nurture a group of teachers to implement creative science and engineering teaching; bring in changes in teaching pedagogy for inculcating innovative strategies for instruction and assessment. We need to develop innovative learning aids for STEM education. To develop, recruit and retain a pool of one lakh excellent quality STEM teachers.	*UGC + AICTE to set up a 10-member* Working Group *to workout necessary intraventions and come out with a roadmap.*	*1 year*	
14.	Introduction of B.Tech. (Vocational) in most conventional B.Tech. disciplines at a massive scale. The curriculum of these programmes (in various disciplines) be so designed that there is a clear-cut dominance of skills-based courses. Admission norms to B.Tech. to be made restrictive thus filtering of candidates for B.Tech. (Voc). There should, of course, be enabling provisions for horizontal mobility between these two programmes in first two years.	*AICTE*	*Immediate*	Leveraging 'Choice-based credit system'.

S.No.	Recommendations	Proposed Action	Expected Time Frame	Remarks
15.	Aligning engineering education with the economy and society of the region. A comprehensive GIS (Geographical Information System) supported profile of the region and people to be used to introduce the programme. Curriculum to expose students to history, culture, industry and the economy of the region. Also, linking programme with organised industry (large and medium) of the region, to build close linkages with the institution for their requirement of manpower, skill development, upgradation, appropriate/ requisite research and development support, etc.	*AICTE:* *3-member high power committee: To fine tune existing formal and informal set up and recommend further action.*	*6 months*	
16.	Experimental introduction of teaching programmes in B.Tech. (integrated engineering). An entirely broad-based programme that everyone has to go through and further specialisation only at the PG-level like what happens in law, medicine etc. Cross-disciplinary exposure that student receives right from the beginning in such a curriculum may spur innovation and creativity in them. Also, it is a requirement of small-scale industrial organisations, which is a necessity with huge scope in a country like ours.	*AICTE*	*Immediate*	**Game Changer**

S.No.	Recommendations	Proposed Action	Expected Time Frame	Remarks
17.	Integrating skills into the formal education system. Introduce skill-based courses to the vast list of available courses in the existing programmes and encourage all possible combination among the traditional courses with skill-based courses.	*UGC and AICTE with immediate action in consonance with the Ministry of Skill Development and Entrepreneurship.*	*Immediate action.*	
18.	Proposal for establishment of *Indian Education Services* in the formal sector and at the national level.	*MHRD: 3-member high power committee to work out its long-term impact and feasible line of action.*	*Immediate action*	
19.	Hand holding of private institutions. There must be some teachers selected, appointed and then deputed by the affiliating university in private engineering colleges and by the respective government in case of private universities. These teachers will be transferrable. We ought to ensure that rapid expansion does not result in massification minus quality.	*UGC and MHRD to instruct universities and institutions for appropriate action.*	*Immediate action.*	

S.No.	Recommendations	Proposed Action	Expected Time Frame	Remarks
20.	The universities which are giving doctorate degrees in engineering streams will have to be monitored very carefully to avoid substandard Ph.D. thesis. While increasing the number of Ph.D.s in STEM areas is important, weeding out of poor quality thesis and linking the research to end-users should be made priority.	*UGC AICTE for immediate action.*	*Immediate action.*	
21.	To substantially increase and sustain public and youth engagement with STEM and to improve the STEM aesthetic experience among the masses.	*MHRD + Ministry of Cultural Affairs: Joint Cell: to prepare a concept document and suggest a further line of action.*	*6 months*	**Game Changer**
22.	Management of science education in universities. Integration of agriculture sciences into STEM. Ranking of STEM higher education departments in a very professional manner.	*MHRD to set up a high-powered committee to workout modalities for integration of different diversified disciplines.*	*6 months*	
23.	Plan national-level specialised institutions in areas where the impact is expected to be the highest and for the long term. For example, Artificial Intelligence, cyber security, climate change, event-driven business ecosystem and Internet of Things etc.	*MHRD + MCA (Ministry of Corporate Affairs) to set up a Joint Committee to identify and come up with a 10 year roadmap.*	*6 months*	

S.No.	Recommendations	Proposed Action	Expected Time Frame	Remarks
24.	Setting up of an institution for popularisation of Science.	*VIF to set up a committee with some members who are the authors of this report and some other eminent scientists and engineers.*	*1 year*	To start as a centre in VIF and to evolve as an Institution in about 3 years' time **Game Changer**

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The Vivekananda International Foundation is an independent non-partisan institution that conducts research and analysis on domestic and international issues, and offers a platform for dialogue and conflict resolution. Some of India's leading practitioners from the fields of security, military, diplomacy, government, academia and media have come together to generate ideas and stimulate action on national security issues.

The defining feature of VIF lies in its provision of core institutional support which enables the organisation to be flexible in its approach and proactive in changing circumstances, with a long-term focus on India's strategic, developmental and civilisational interests. The VIF aims to channelise fresh insights and decades of experience harnessed from its faculty into fostering actionable ideas for the nation's stakeholders.

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