WHITHER SCIENCE EDUCATION IN INDIAN COLLEGES?

Urgent reforms to meet the challenges of a Knowledge Society

Dr. Catarina Correia | Dr. Leena Chandran-Wadia | Radha Viswanathan | Adithi Muralidhar

Students of the Pardhi community (a nomadic tribe) from Yamgarwadi, Maharashtra, explain the structure of DNA Sir Harold Kroto, Nobel laureate in Chemistry in 1986, during an interaction at a function organised by the Observer Research Foundation Mumbai

Foreword by Bharat Ratna Dr. C.N.R.Rao

"Every classroom in the country must echo with the excitement and curiosity of science"

Observer Research Foundation Mumbai

Ideas and Action for a Better India

FOREWORD

Every classroom in the country must echo with the excitement and curiosity of science

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I am delighted that the Observer Research Foundation Mumbai has produced a report titled 'WHITHER SCIENCE EDUCATION IN INDIAN COLLEGES? Urgent Reforms to Meet the Challenges of Knowledge Society'. It is a comprehensive and well-researched study of how science is taught and learnt in Indian colleges. It also suggests how science should be taught and learnt, so that it benefits the students, becomes relevant to society, aids the goal of nation-building in multiple ways, and contributes to the reservoir of human knowledge. I compliment the authors of the report — Dr. Catarina Correia, Dr. Leena Chandran-Wadia, Radha Viswanathan and Adithi Muralidhar.

The subject of this report appeals to me since I have been a student of science for long, a teacher of science, a practicing scientist for over five decades, and a participant in policy making at the national level. I am glad to have been asked to share my thoughts on it.

Science touches every realm of living. Indeed, science is the script-writer of modernity since life in modern societies is unthinkable without the countless benefits of scientific research. If we want to see India's accelerated rise as a strong, prosperous and self-confident nation occupying its rightful place in the modern world, our country must pay far greater attention to the quality and relevance of science education and scientific research than has been the case so far.

Science has its origins in the passion, curiosity and creativity of young minds and these traits are the critical building blocks of a nation's scientific temperament and indeed achievement. India has a rich scientific heritage that is both ancient and modern and this has to be revived if it has to scale the pinnacles of scientific achievement.

My vision for science education is that every classroom in the country – from the kindergarten to the most advanced research laboratory – must echo the excitement and curiosity of science. If we are able to excite young minds about science, that would propel them to take up careers in science. If we are able to sow the seeds of scientific curiosity and endeavour in the young fertile and creative minds of today, the nation will reap benefits from a robust population of enthusiastic and committed researchers, teachers and science communicators.

In this context I recall the words of Professor C.V. Raman, the Nobel laureate, whose visit to my school when I was 11 years old was a source of great inspiration to me:

> "I would like to tell the young men and women before me not to lose hope and courage. Success can only come to you by courageous devotion to the task lying in front of you and there is nothing worth in this world that can come without the sweat of our brow. I can assert without fear of contradiction that the quality of the Indian mind is equal to the quality of any Teutonic, Nordic or Anglo-Saxon mind. What we lack is perhaps courage, what we lack is perhaps the driving force which takes one anywhere. We have, I think, developed an inferiority complex. I think what is needed in India today is the destruction of that defeatist spirit. We need a spirit of victory, a spirit that will carry us to our rightful place under the sun, a spirit which will recognise that we, as inheritors of a proud civilization, are entitled to a rightful place on this planet. If that indomitable spirit were to arise, nothing can hold us from achieving our rightful destiny."

These words continue to inspire me. Nothing kindles, and sustains, interest in science in bright young minds more than a motivating appeal to overcome odds in the pursuit of excellence.

I was pleased to see the cover photo on this report which shows Nobel laureate Prof. Harold Kroto's interaction with the high school students of a tribal settlement in Maharashtra. This would have been no less inspiring for those first-generation school-going students who are blessed with the same quality of intellect as the children studying in elite schools. If they get good educational opportunities to develop their innate interest in science, they are bound to become as accomplished in their professional lives as the children from privileged backgrounds. I laud the Observer Research Foundation for having made this interaction possible.

Sadly, the value system in our society today does not favour the development of science as a first-choice career option for bright students since it gives greater importance to material pursuits and accomplishments over intellectual development. This has led to a career in science being devalued compared to other professions. As a result, knowledge creation has suffered and the input of energy and enthusiasm into the scientific search for solutions to our nation's problems, which are in many ways common to large populations residing in other countries around the world, has greatly reduced. The status of the teacher, once hallowed, has been seriously eroded.

We should not ignore the fact that science education in colleges has been a weak link in our overall national strategy for development of science. We have an examination system, not an education system. Many of our universities have become examination-conducting centres, and not centres for knowledge creation and knowledge dissemination. This is not only true of science education, but also of education in general.

I entirely endorse the recommendation made in the report that we should end bureaucratic control and interference of politicians in the functioning of universities and colleges. We must recognise that excessive bureaucratic controls have stifled scientific progress. The paucity of quality institutions for the propagation of science has stunted the growth of scientific talent in the country; we have been slow in building them. One way to de-bureacratise the education system is to make colleges with a reputation for quality — and there are several of them in the country — autonomous. It is a good idea to give effective autonomy – academic, financial, administrative – to all colleges with proven skills in running institutions.

Another idea I have liked in the report is to make science education in Indian colleges relevant to the needs of our society so that education becomes an effective contributor to solving the nation's problems and enhancing the employability of our large population of youth. When we talk of India's scientific achievements, we often mention our advancements in atomic energy and space, which are regarded as 'big' science. However, accomplishments in 'small' science have the potential to benefit India even more. Small science's potential to solve mankind's problems such as food security, energy security, cure for illnesses and mitigating the effects of climate change have far-reaching effects on the lives of ordinary people. As has been rightly pointed out in the report, this will require empowering our teachers to introduce innovations that will make the curriculum relevant to local conditions and strengthen college-industry, college-agriculture and college-society interaction.

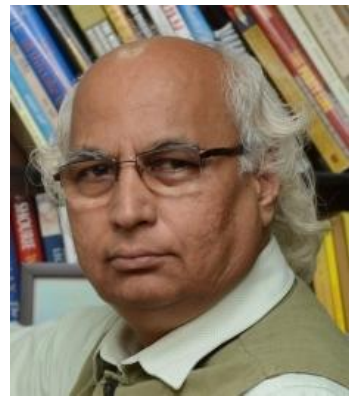
I cannot overstate the need to prioritise equity and excellence at all levels of education. Spanning the entire spectrum of education we need institutions, teachers, bureaucrats, and managements that work in consonance to make India a global leader in science. Specifically, we need hundreds of institutions of excellence like the Tata Institute of Fundamental Research (TIFR), Indian Institute of Science (IISc) and the recently established Indian Institutes of Science Education and Research (IISER). Such institutions would help to employ a large number of young scientists and give them opportunities for professional development. While we need to set up new institutions of excellence, the real challenge — which is also a big opportunity — is to improve our universities and affiliated colleges. There is simply no other choice. This message comes very clearly and starkly from the report by Observer Research Foundation Mumbai.

I appreciate the effort of researchers of the Observer Research Foundation who have produced this timely and thought-provoking report. I hope that it will receive due attention from all concerned.

June 2014

PREFACE

Why should India, an *upaasak* of *gyan* and *vigyan*, tolerate mediocrity in science education?



SUDHEENDRA KULKARNI
CHAIRMAN, ORF MUMBAI

The photograph on the cover of this report has a story.

It shows Sir Harold Kroto, who won, along with two others, the 1996 Nobel Prize for Chemistry — specifically for his discovery of Buckminsterfullerene (C_{60}), a new form of carbon structure shaped like a tiny soccer ball that has amazing applications in nanotechnology. He was interacting with a group of secondary school students from Yamgarwadi village near Solapur, a poverty-ridden part of southern Maharashtra. The children, who belonged to nomadic tribes, showed him several amazing scientific experiments, using simple and low-cost gadgets, which they had themselves made with the help of their teachers and using local materials.

For example, this is how a seventh class student explained in Marathi, his mother tongue, the concept of convex and concave lenses using the sole of a worn-out rubber slipper, which had five-six equidistant holes punched in lengthwise, with a soft drink straw stuck in each of them. "Imagine the sole to be a lens and the straws to be sun rays. I bend the sole to make the straws point inwards. This is how a convex lens works. When I bend it the other way to make the straws point outwards, it becomes a concave lens."

The students also demonstrated the structure of DNA using a simple, self-made, lowest-cost device.

Dr. Kroto could not hide his astonishment and admiration.

If first generation learners from a poor tribal community have the intellect to wow a Nobel laureate scientist, then nobody can doubt that India, with a population of 1.2 billion people, has the potential to emerge as a front-ranking nation in science and technology … provided our system of school and college education ends its preference for mediocrity.

The occasion of Dr. Kroto's interaction with these bright students of science from rural Maharashtra was a talk by him on nanotechnology, which the Observer Research Foundation had organised in 2011. The venue of the talk was a slum colony in Mumbai. Dr. Kroto has been an avid champion of the people's science movement, whose motto is —'Science for the People, Science to the People, and Science by the People'. The Vega Science Trust set up by him gives top-notch scientists in the world a broadcasting platform to educate students, teachers and the general public directly about exciting and useful scientific matters.

The students who demonstrated scientific experiments to him belong to tribal communities which suffer from extreme poverty and social exclusion, and rank lowest in formal school education. Yet, there is a silent social revolution taking place in their communities, thanks to the struggles and constructive activities led by a group of socially committed activists. During my visit to Yamgarwadi, I was amazed by their children's scientific knowledge about the environment around them. They knew the medicinal properties of all the locally grown 'weeds'. They could identify different birds from their sounds. Accustomed to sleeping in ramshackle tents in the open, they could name the stars in the night sky. In a little room that served as the 'science laboratory' in the school, all the various types of snakes, crabs and scorpions kept in specimen jars had been caught by the children themselves. And these kids were also incredibly talented in singing, dancing, playing local sports, and using their magical hands to create things of beauty in wood, mud and grass!

Thus, a world-renowned scientist's talk on nanotechnology, at a slum colony in Mumbai, with the participation of tribal students from a remote village, became a rendezvous for high science and low science, both wedded to the common goal of promoting the welfare of humanity.

We have deliberately used this photograph for the cover of this report, even though the report itself is about the challenges of science education in Indian colleges. Its message transcends its context, and compels us to think of the wide chasm between India's enormous need and potential in the field of science-propelled development on the one hand, and, on the other, the current ability of India's system of science education to fulfill the need and tap the potential.

Viewed from a holistic perspective, the biggest challenge of science education in India's education system (school, college and university system) is five-fold:

- How to ignite the scientific spirit in all sections of Indian society;
- How to develop curiosity in, and love for, science among young Indians, enabling more and more of them, especially those belonging to excluded communities, to pursue science learning and scientific research as attractive career options;
- How to integrate high science and low science – modern science of the scientists and traditional science of the masses – and make both relevant for the pressing needs of India's all-round development;
- How to integrate knowledge of the material world, and knowledge about material development, with universal ethical values;
- How India can contribute its full share to the rapidly expanding global pool of science (*vigyan*) and all other inter-related streams of knowledge (*gyan*) for the collective and peaceful development of humanity.

* * *

India has been an *upaasak* (worshipper or extoller) of *gyan* and *vigyan* since time immemorial. The best minds in India in every era were engaged in harmonious pursuit of knowledge about man's outer universe and also his inner universe, both aimed at enabling human beings to live in accordance with the purpose for which they have been created. Application of that knowledge for the fulfillment of the material needs of society was one aspect of that pursuit. The other aspect was the use of that knowledge for people to realise the higher purpose and possibilities of life.

Those who were engaged in pursuit of scientific knowledge, and who developed various technologies, products, skills and artistic traditions for this purpose, enjoyed high social prestige. This meant the entire working population. This also meant that all the categories of working population were repositories of some or the other kind of traditional knowledge, both scientific and artistic. Ancient India did not erect a wall between science and art, or between science and spirituality.

Another important point, India welcomed and assimilated knowledge that originated in other parts of the world, just as it sent out "knowledge workers" to other parts of the world to propagate what it had learnt.

There were, of course, aberrations and conflicts in Indian society from time to time, which gave rise to discrimination and injustice. But, by and large, the identity of India was that of a KNOWLEDGE SOCIETY. Had this not been the case, Indian civilisation would not have survived the vicissitudes of thousands of years of history. The many scientific and technological achievements of ancient and medieval Indian science are, sadly, not included in school and college curricula.

The British rule exposed India to the rise of modern science in the West. This was undoubtedly a positive development. However, it also had a negative fallout. It destroyed, to a large extent, India's traditional education system. Additionally, it created a mindset of inferiority among, and about, those who could not find a place in the "modern" economy or "modern" education. Even after nearly seven decades of independence, India has not quite liberated itself from this mindset. A large section of our population is regarded as lacking in education simply because it is illiterate or semi-literate. And the criterion of knowledge has come to be equated with a college degree – any degree.

This tight equation between a degree certificate and education has created several distortions, both in society and in the system of education itself. It has placed disproportionate emphasis on standardised examinations and the students' ability to score well in them. On the one hand, this has reduced most Indian universities to examination-conducting centres. On the other hand, this has forced most students and teachers to resort to rote learning and teaching. The impact of this on the quality of science education in colleges has been particularly deleterious. Memorisation of facts and formulae has triumphed over mastery of concepts, independent and creative thinking, integrative thinking that connects understanding of different subjects, and ability to apply that understanding to solve practical problems of society.

The problem is worsened by the vice-like bureaucratic control of the education system, in which neither students and teachers nor college managements have the freedom and flexibility to introduce innovations in learning and teaching. There is very little focus on supplementing and enriching textbook learning with college-industry, college-agriculture and college-community interaction. No wonder, most graduates are unemployable. No wonder, most of them end up pursuing careers unrelated to the subjects of their study. No wonder, most of them discover that much of what they learnt has very little relevance in their working life.

And no wonder, science is not a preferred academic stream for students, even though this fact has been a matter of lament in the speeches at every session of the Indian Science Congress.

What a colossal waste of precious human resources.

There is also another serious aspect of the problem. The Gross Enrolment Ratio in college education in India stands at around 20 percent, up from 12.5 percent in 2007. This is no doubt an achievement as far as it goes, even though there are sharp regional, social and gender disparities. India could even achieve a GER of 30 percent by 2020. However, quite apart from the mediocre quality of education that many of the college students will receive, what about the remaining 70 percent of the population in the college-going age group? A small section of them is sought to be covered by the skill development mission, but this mission is again driven solely by quantitative targets with little attention paid to quality and employability outcomes. There is also the danger of skill development being carried out with no relation to basic understanding of scientific concepts and theory.

Thus, India is facing two kinds of disconnect: a formal science education pedagogy in colleges that is too theory-based and is disconnected from the practical world; and a large work force in the informal sector of the economy whose practice is disconnected from science education.

This is not to deny India's remarkable achievements in various fields of science and technology. They are indeed a source of national pride. But while rejoicing in these achievements, we cannot be blind to the fact that they are far below our needs as well as our potential.

Therefore, if the strategic goal of science education in India is 'Science for the People, Science to the People, and Science by the People', then it is obvious that we must critically review whether this goal is reflected in the working of our schools, colleges and universities. This report by ORF Mumbai is an attempt at doing such a review. We do not claim it to be comprehensive. Indeed, its purview is only science education in colleges. Nevertheless, our study is certainly objective, and is motivated by a deep concern that perpetuation of the numerous shortcomings in the system (which have been boldly highlighted in our study) would shatter the dreams of hundreds of millions of young Indians.

Our study also recommends specific and practical reforms for the removal of these shortcomings. Some of these urgently needed reforms are:

1. End bureaucratic control and interference of politicians in the functioning of universities and colleges.
2. Give automatic, complete and effective autonomy – academic, financial, administrative – to all colleges with 'A' grade in NAAC accreditation.
3. Completely overhaul and update curricula – and do so on a frequent basis – to capture fast-paced developments in the world of science and technology. As part of this, create a fast-track plan for the academic progress of exceptionally intelligent students.
4. End rote teaching and learning. The focus of science education should be on "how to learn", and not merely on "what to learn".

5. Make world-class ICT infrastructure, along with creative digital content, available to all science colleges.
6. Empower teachers and college managements to introduce such innovations as will make the curriculum relevant to local conditions and strengthen college-industry, college-agriculture (especially in rural areas) and college-society interaction with a practical, problem-solving and employability-enhancing orientation.
7. Taking the college to the community, and bringing the community to the college, should be a mandatory part of college activities. This will require making appropriately designed courses / workshops available in non-English languages to community learners. This will also require a special effort to discover, capture and popularise traditional scientific knowledge.
8. Introduce more and more inter-disciplinary science subjects, as well as humanities and character development subjects, in the curricula.
9. Since science and technology are the biggest drivers of wealth creation, research and development, commercialisation of R&D, and promotion of entrepreneurship should be actively encouraged both among teachers and students.
10. Teacher recruitment and promotion must be strictly on merit basis. Teacher training and re-training on a regular basis must be mandatory. Good teachers should have ample opportunities to participate in scientific conferences in India and abroad.

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I compliment my colleagues Dr. Catarina Correia, Dr. Leena Chandran-Wadia, Radha Viswanathan and Adithi Muralidhar for producing this important study. Their passion for the subject is evident in each page of the report.

I would like to thank Dr. Sanjay Deshmukh, professor of Life Sciences at University of Mumbai, for guiding this study in its initial stages.

The purpose of producing this report is to contribute to the current (unfortunately, rather weak) national debate on science education and scientific research in India. We urge all the stakeholders – policy makers in central and state governments; leaders of universities and research institutions; leading scientists; science teachers; managements of science colleges; thought leaders in industry, agriculture, society and mass media; students and parents – to take due note of this report and make it a subject of wider action-oriented discussion.

Needless to add, your critical comments are most welcome.

June 2014

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EXECUTIVE SUMMARY

India has a rich history of science and technology, which is embedded in our intellectual, material and cultural heritage. Though many of our scientific achievements have been creditworthy and a boost to the economy, it seems that the beacon of advancement in science and technology has dimmed in the recent past. The government has envisioned an ambitious goal to make India a "global leader in science" by 2020, by significantly increasing the investments in S&T, research, education, and innovation over the next five years. The Science, Technology and Innovation Policy 2013, coming as it does in the "Decade of Innovation" (2010-20), will advance India's prowess in a number of strategic sectors and will emphasise S&T led innovations by linking contributions of the scientific research and innovation system with the inclusive socio-economic growth agenda.

It undoubtedly follows that the highly-skilled labour force for S&T led development in India must emerge from our colleges and universities. While the government has been working to improve the equity, quality and access in higher education, it seems that there is a wide rift between the national vision for science and the ground reality. Even though enrolment in science courses in colleges has been sustained and improving over the years, the quality of science education remains rather variable. There are a few world class institutions followed by a vast majority of institutions of indifferent quality. Further, with India harbouring the largest youth populations in the world, it is interesting to note the trends amongst those who choose careers in science. It seems that the lack of high quality institutions and universities, dearth of opportunities for attractive employment, weak focus on entrepreneurship, lack of opportunities for research and a curriculum disconnected from the practical world are some of the many reasons as to why the younger generation is seen to opt out of careers in science.

This report by the Observer Research Foundation Mumbai titled **"Whither Science Education in Indian Colleges?"** places its study of tertiary science education in India in the context of reclaiming India's space in science by strengthening the college education system which is a building block for preparing the human resource needed for scientific advancement. The study involved primary qualitative research that comprised interviews and consultation with major stakeholders like principals, teachers, educationists, students, researchers and employers, and secondary research that included review of existing policy documents and scientific literature. A roundtable was also organised by ORF Mumbai, on "Whither Science Education in Indian Colleges today?". Different stakeholders came together to deliberate on the pressing issues currently prevailing in science education.

This report identifies several factors responsible for the falling standards of Indian science colleges as centres of learning and research, which need to be urgently addressed. Poor quality of teaching, inadequate infrastructural facilities, inadequate funding, limited employment options, dearth of good science teachers at primary and secondary levels and a serious lack of inspiring academic leadership that conveys a vision for science and research are some of the issues discussed. Additionally, the report also dwells on concerns regarding the outdated curricula, the excessive focus on examinations, poor teacher development programmes, low motivational levels among teachers, and the schism between academic learning and the needs of industry, agriculture and socio-economic development in general.

The study also raises concerns on how the governance system in higher education has not kept pace with the massive expansion of universities. It reveals the unfortunate state of some of the best colleges in the country which fall short of world standards in various sectors from teaching quality to research output mainly due to poor and faulty governance at the university level. The report urges that it is time for the Indian universities to work towards reversing a long trend towards obsolescence, and to lay the foundations of a world class and broad based R&D infrastructure.

The report also makes a few recommendations by suggesting potential solutions for improvement of our science colleges. A special case for autonomy of educational institutions is made, which would help in building capacity in these centres of learning. The report discusses how this can be achieved by encouraging cluster college models in the tertiary education system, with specific recommendations on how to initiate and sustain such a set-up. Academic autonomy with an administrative ethos that is democratic, decentralised and consultative in nature coupled with unbiased regular performance review and measures for creating strict accountability are of crucial importance to achieve a holistic and high standard of academic excellence. Finally, the report makes some recommendations on how to improve leadership and accountability, how to upgrade curricula, and how to use and integrate Information and Communications Technology in education to improve quality of science teaching and learning, in order to create a talent pool for a vibrant scientific community in India.

Improvement of the existing system of higher education mandates changes and owing to India's immense diversity in her citizens, it is but obvious that no single model of science education and research would cater to the needs of this diverse nation which nurtures both curiosity and creativity amongst her citizens. Specifically, there is a need to integrate knowledge about India's rich heritage of scientific and technological knowledge in science education in schools and colleges.

However, there are some basic steps that can be taken to provide a relatively better standard of education, to integrate high quality research with undergraduate teaching and to enhance the academic and industry linkages in the country. The report appeals to the policy makers and implementers that reforming India's science education scenario should be seen as the primary step to unlock her immense human resource potential to enhance India's global competitiveness.

"No national scientific enterprise can be sustainable in the long term if it does not contain generous room for curiosity-driven research. While the technological outcomes and social benefits of basic science are almost always long-term and rarely predictable, such science creates and consolidates overall competence and intellectual diversity"

(A Draft Vision Document for Indian Science,
Indian National Science Academy, 2010)

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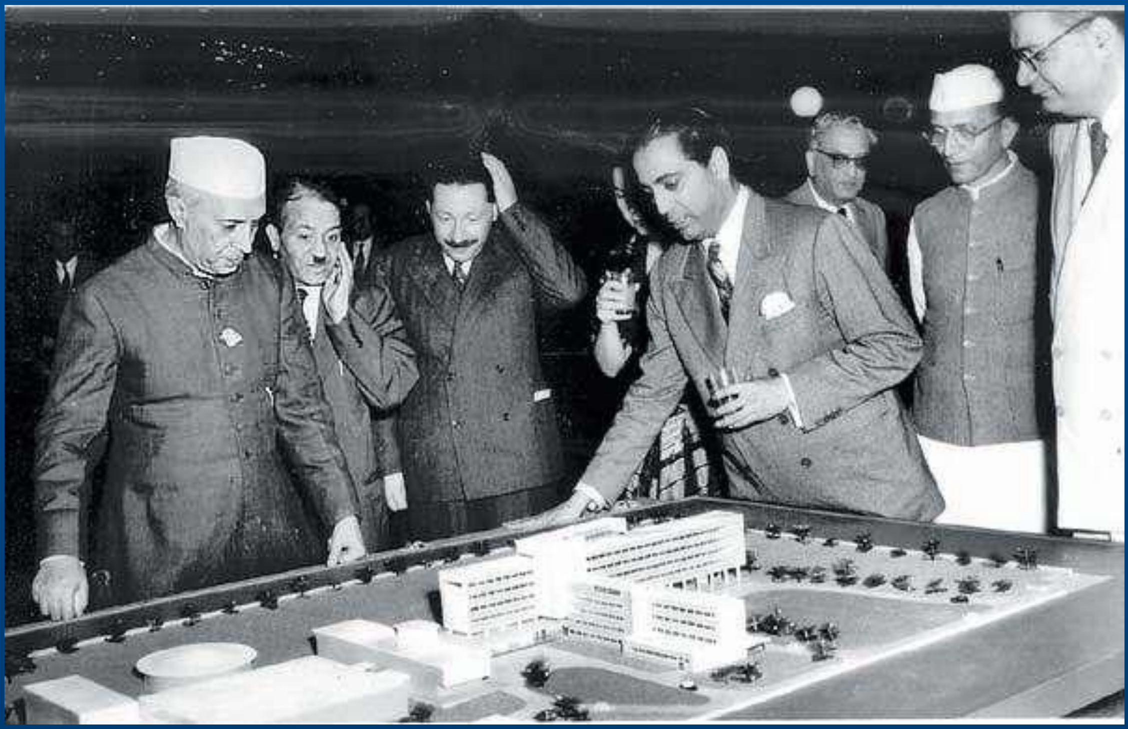
1. Introduction

"It is science alone that can solve the problems of hunger and poverty, of insanitation and illiteracy, of superstition and deadening custom and tradition, of vast resources running to waste, or a rich country inhabited by starving people... Who indeed could afford to ignore science today? At every turn we have to seek its aid... The future belongs to science and those who make friends with science."

Pandit Jawaharlal Nehru



India prides itself in a great tradition of scientific learning dating back to the Vedic times. Aryabhata who lived and studied in Pataliputra (modern Patna) in the 5th century, wrote his treatise Aryabhata – comprising one hundred and twenty one cryptic verses. This was the basis of every subsequent text on Indian mathematics and astronomy. From Aryabhata in the 5th century to Bhaskara in the 11th century, the period when Europe was nowhere on the intellectual scene, the world looked to India for new ideas[1]. In the 11th century, Al Beruni translated the Sanskrit works by Brahmagupta and others on astronomy and mathematics. However, this tradition could not be sustained in later centuries.

> "As the period known in Europe as the age of discovery merged into an age of enlightenment, India marked not a renewal, but the terminal decline of a tradition of learning going back three thousand years to the Vedic times. No worthwhile new mathematical or astronomical knowledge emerged in Kerala or in India as a whole after about 1600 until we come to modern times." [2]

Prof Jayant Narlikar[3] talks of the "*resurgence of the old spirit of scientific enquiry in the beginning of the twentieth century, when even under the colonial rule, Indians began to assert their intellectual potential in science. Srinivasa Ramanujan, Jagadish Chandra Bose, Meghnad Saha, Satyendra Nath Bose, C.V. Raman are examples of this new resurgence... These people were all distinguished as teachers who inspired younger generations of students. Succeeding generations of students in the 1930s, 1940s and 1950s were motivated by them to take up research and teaching in basic sciences.*" [4]

After Independence, India's visionaries, led by Prime Minister Jawaharlal Nehru – who saw a close link between science and socio-economic development – laid the foundation for a strong science and technology ecosystem. Dr Homi Bhabha, world-renowned scientist and a great institution builder, set up the Tata Institute of Fundamental Research (TIFR) and the Bhabha Atomic Research Centre (BARC). He also chaired the Electronics Committee which prepared a road map for electronics development in India. Dr Vikram Sarabhai another doyen of Indian science, prepared the ground for the establishment of the Physical Research Laboratory and the more spectacular Indian Space Research Organisation (ISRO). The '50s and '60s saw the establishment of the Indian Institutes of Technology (IITs) as premier institutes of 'national importance'.

While post-colonial India's achievements in science have been creditworthy, the advancement of science and technology ceased to be pursued with the same sense of purpose in the subsequent decades. In 2005 the Scientific Advisory Council to the Prime Minister of India[5] (SAC-PM), the top body representing the cream of the scientific establishment, was reconstituted after fifteen years to deliberate on science and technology policy issues. To see India "as a global leader in science" is the resounding vision of the Scientific Advisory Council, which envisages the Union government spending at least 2.5 percent of the GNP for science by 2020 and greater collaboration between scientific

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[1] P.P. Divakaran, Calculus Under the Coconut Palms: The Last Hurrah of Medieval Indian Mathematics, IUCCA, Pune

[2] ibid

[3] Renowned astronomer and former Director, Inter-University Centre for Astronomy and Astrophysics, Pune.

[4] Jayant V. Narlikar, How to Recapture the Thrill for Basic Sciences in Higher Education, UGC Golden Jubilee Lecture Series, 2002-03

[5] Website of Scientific Advisory Council to Prime Minister - http://sactopm.gov.in/

communities of India and other countries across the globe. The SAC-PM recommends that "educational and research institutions in the country would have to go more global and make special schemes for exchange of scientists at various levels with selected partner nations or institutions across the globe[6]".

Significantly, on the issue of establishing world class universities, this apex body for Science has categorically stated: "As the present system is by common consent inimical to the success of such a project, a new framework has to be devised" (p.22).Their criteria for defining a new framework include:

- Seeking dynamic leadership at the top and providing "real" autonomy with minimal bureaucratic and political interference;
- Getting the best faculty and establishing a proper faculty promotion policy;
- Establishing the best facilities;
- Welcoming private investment and support;
- Assembling a diverse student body balancing excellence and inclusion;
- Combining undergraduate teaching and world-class research.

This report by the Observer Research Foundation Mumbai tracks the long road India must tread to reclaim its rightful space in science. This study, the result of primary qualitative research and consultation with primary stakeholders[7], reveals how even the colleges accredited 'A' Grade, by the national accrediting body (NAAC) fall seriously short of world standards in terms of well qualified faculty, research output or infrastructure indicating that even our best universities and colleges need to become better. The report underscores the need to reform the science education landscape as the first step to unlock India's human resource potential for enhancing India's global competitiveness.

While, the existence of a handful of institutions of international repute (like the IITs, IISc[8]) is heartening, it is insufficient to fulfil the grand national vision. The findings of this report show that there is a wide chasm between the national vision for India to be a "global leader in science" and the ground reality in the educational institutions that prepare students for careers in science. It is this harsh reality that feeds the popular perception of science being an unwise career choice that fails to attract the most promising talent, though this waning interest in science as a career is by no means unique to India. In turn, scientific talent needs a suitable ecosystem in which it can be nurtured. The two pillars for the growth of science – Education and Ecosystem – have a salutary effect on each other and therefore need to be improved and strengthened in a collaborative and coordinated manner. The following pages shed light on India's performance in Science, Technology and Innovation measured against the best around the world, and highlight how far from perfect the education system and the ecosystem in India are.

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[6] http://www.dst.gov.in/Vision_Document.pdf (p27)
[7] Primary stakeholders included principals, teachers, educators, students, researchers and employers.
[8] http://timesofindia.indiatimes.com/home/education/news/IITs-find-a-place-in-2014-world-ranking/articleshow/31043491.cms

Investment in R&D: The present level of investment in the country for Research and Development (R&D) in science and technology sector is 0.88 percent of GDP[9]. The private investment in R&D as a percentage of GDP in India is only 0.23 percent which has not kept pace with many developed and emerging countries in the world. More than 55 percent of Gross Expenditure in R&D (GERD) in the last few decades is consumed by the strategic sectors of defence (DRDO), atomic energy (DAE), and space (ISRO). Thus, India, with one of the lowest R&D/GDP ratios, is also expending the resources in areas that have a weak connection to industry, thereby missing out on opportunities for economic growth as seen in the case of South Korea, China or Israel. More than a quarter of R&D investment goes towards basic research, against 5 per cent in China and 17 per cent in the United States (Ghosh, 2012). Table 1 shows the comparative science expenditure of developed and developing countries as per a recent study (Bound and Thornton, 2012).

	India	Brazil	China	UK	US
Population (World Bank,[64] 2010)	1,170,938,000	194,946,470	1,338,299,512	62,218,761	309,050,816
GDP per capita (Current US$, World bank 2010)	1,477	10,710	4,393	36,100	47,184
GDP Growth (Annual %, World Bank, 2010)	9.72	7.49	10.30	1.25	2.85
GERD (% of GDP, World Bank, 2007)	0.80	1.10	1.44	1.82	2.72

Table 1: Comparative Science Expenditure
Source: Bound and Thornton, 2012

The R&D investment in industry has paid rich dividends in South Korea. In the 1990s, the South Korean government poured $3.5 billion dollars into twenty-three projects in setting up centres of excellence aimed at improving competitiveness in fields such as biosciences, nanotechnology and space technology. In 2008, South Korea devoted $ 286 million to R&D, accounting for 3-4 percent of GDP, equalling about half of the figure for the U.S. Also, the government employed over 4,000 researchers in its R&D labs, nearly doubling the figure in a matter of eight years. Private facilities accounted for two-thirds of both total spending and researchers, while eighty percent of the rest worked at universities. Unsurprisingly, most corporate researchers work on applied technologies (Campbell, 2012).

Out of India's already low investment in R&D, what reaches universities and affiliated colleges is meagre. For the decade 1997-2007, universities were allocated just 5 percent of GERD (Krishna, 2013) while the lion's share went to government bodies. The OECD Better Policy Series 2012, in the chapter *Strengthening Innovation* states that Universities and Public Research Institutes (PRIs) strongly

[9] Status of Scientific Research in the Country , 04 March 2013, Press Release, http://pib.nic.in/newsite/PrintRelease.aspx?relid=92924

dominate India's R&D system and 73 percent of public research is funded by block grants - reflecting a lack of competition mechanisms in the public R&D system. But since it is also true that hardly 15 percent of our universities come under the label of teaching and research universities (Krishna, 2013), most of the funding goes to PRIs. In other emerging economies, while government shares are significant (just over 25 percent in Brazil; around 20 percent in China), they are much lower than India's (close to 70 percent). Figure 1 presents a comparison of R&D resource allocation in different countries.

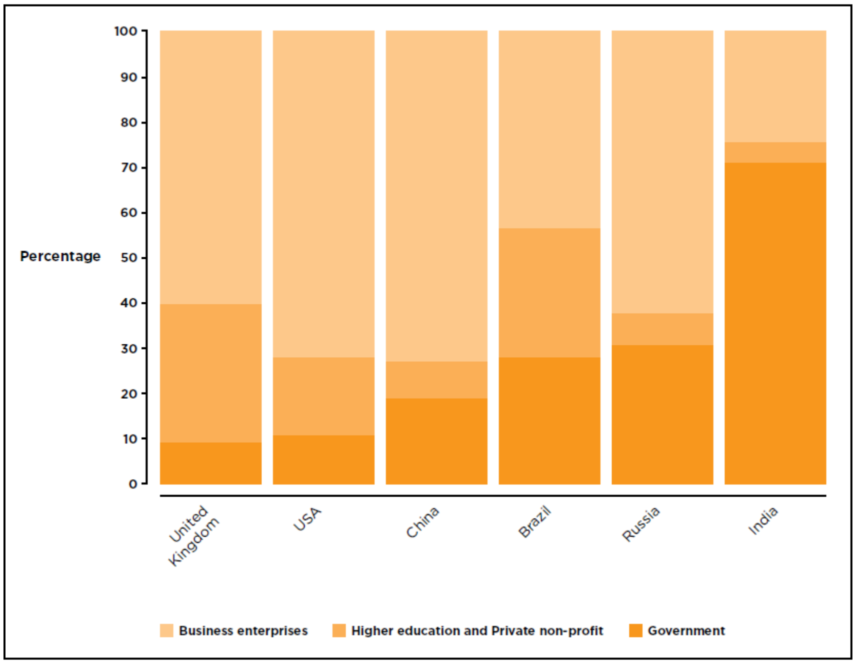

Figure 1: R&D Resource Allocation
Source: Bound and Thornton, 2012

Chinese universities increased their share of GERD from around 5 percent in the 1990s to over 12 percent currently. In China, in the mid-1990s, as part of the national innovation strategy termed 'Project 211', a massive infusion of funds, $7.98 billion, was made for 100 universities. Starting from the late 1990s, with a budget of $4.87 billion, 39 universities were shortlisted under Project 985 to develop a "Chinese Ivy League" (Krishna, 2013).

The pillar of South Korea's Science and Technology policy was the creation of a state-led research and educational capacity, centred on state-run research institutes, and in-house research and development efforts by the large industrial conglomerates (Campbell, 2012).

Universities in the OECD countries accounted for 20 percent and Japanese universities accounted for around 15 percent of GERD in the last decade (Krishna, 2013).

Patents: For research to increase economic competitiveness there must be efforts to commercialise a significant portion of it. While India's patent filings have grown rapidly since the mid-1990s (with a compounded growth rate of 10 percent per annum); China had an annual growth rate of 25 percent during 1995-2007. Patent filings per million people have remained low in India, touching a maximum of six (Ghosh, 2012).

However, as presented in Figure 2, India produces more patents than China per dollar spent on R&D.

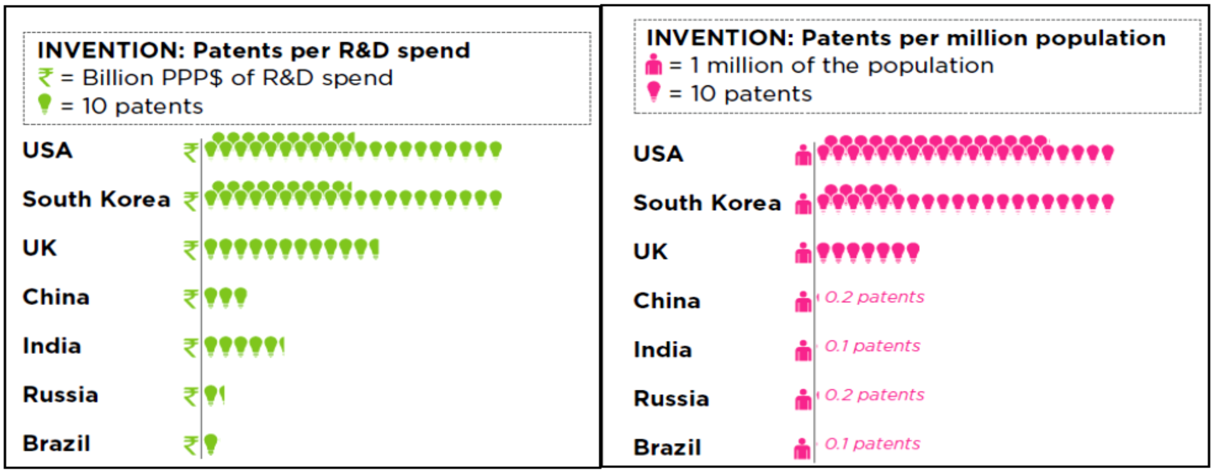

Figure 2: Patents per R&D spend; Patents per million population
Source: Bound and Thornton, 2012

Research publications: According to Elsevier (2012), India's output in terms of articles published per year increased from 41,200 in 2006 to 65,487 in 2010, thus showing an overall high Compound Annual Growth Rate (CAGR) of 12.3 percent. In comparison, countries like China and Iran showed a better rise with 13.7 percent and 25.2 percent CAGR respectively. It is also interesting to note that several developed countries like United States (1.9 percent), United Kingdom (2.9 percent) and Israel (1 percent) showed CAGR much below the world average of 4 percent. Further, a comparison of competencies of research publications in 16 major scientific fields in terms of citation impact revealed that India had a higher value of 0.68 as compared to 0.53 of China during 2006-10[10]. India's output of scientific and technical articles, which stagnated through the late 1990s, began to rise after 2000, and the volume of S&T publications by Indian authors nearly doubled by 2009. India's world ranking however changed only moderately, from 12th in 1995 to 11th place in 2009[11].

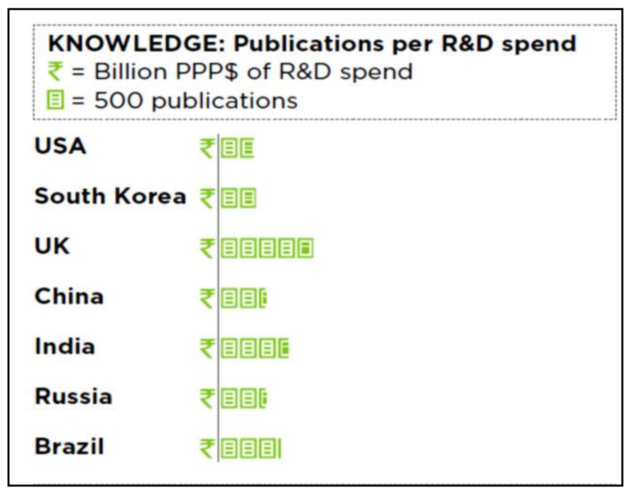

Figure 3: Publications per R&D spend
Source: Bound and Thornton, 2012

[10] Union Minister of Science &Technology and Earth Sciences Shri S.Jaipal Reddy gave this information in reply to a written question in the Rajya Sabha – DST Press release March 4, 2013
[11] http://www.oecd.org, India Brochure 2012

This indicates the level of competition and the race among countries to stay ahead. Nevertheless, Figure 3 shows that India produces more scientific publications per dollar of spending than the USA and China (Bound and Thornton, 2012).

India's record of research publications and patents exposes the underlying weaknesses and clearly establishes the need to improve the quantity and quality of its science human resource with a view to improving its competitiveness and efficiency in serving the cause of inclusive growth, particularly in the areas of food security, energy security, health security, environmental security and employment security.

Human Resources in Science: India has dynamic, developed and diversified industrial and service sectors established on the strength of its own talents. Our technological achievements are substantial and, in certain areas, these are world class. A testimony to India's S&T capability is the recent launch of the Geosynchronous Satellite Launch Vehicle (GSLV-D5) by ISRO in January 2014 – the first successful flight of the GSLV Mark II using the indigenously developed cryogenic engine.

Dr. Michiel Kolman, Senior Vice-President, Academic Relations, at Elsevier, which was commissioned by the Department of Science and Technology (DST) to do a study on International Comparative Performance of India's Scientific Research in 2012, comments that, "India shows a net inflow of scientists, with the productivity of the incoming and visiting scientists being higher than that of the average staying and outgoing scientist; so in fact a case can be made for an Indian 'Brain Gain' rather than the commonly believed 'Brain Drain'."[12]

In its **Major Recommendations & Accomplishments of the SAC-PM[13] (2004 - 2013),** the apex scientific advisory body identifies the lack of strongly integrated programmes involving human resources development as one of the weaknesses that India needs to overcome. This report avers that human resource is the core issue.

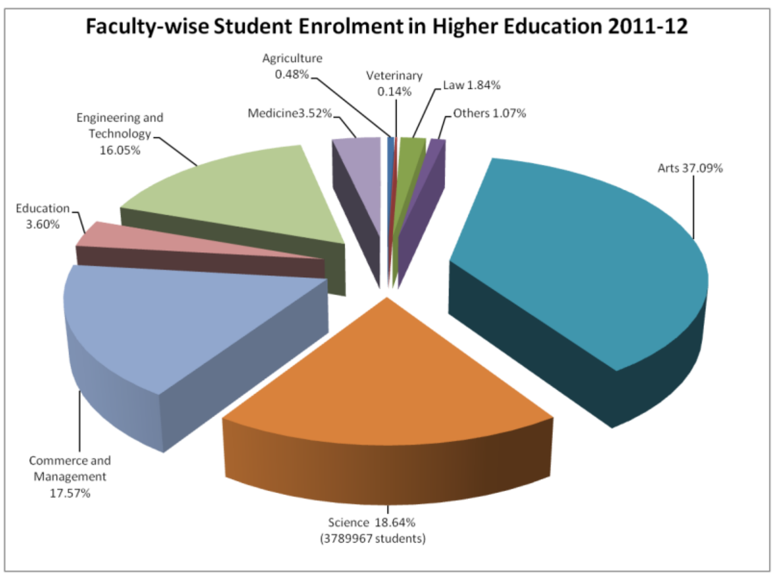

Figure 4: Faculty-wise Student Enrolment in Higher Education 2011-'12
Source: UGC, Higher Education at a Glance 2013

Although the communication put out by the Ministry says that "there is no lack of dedicated scientific personnel in the country"[14], available statistics points to the fact that the core Human Resource in Science and Technology (based both on education and occupation) is actually very small in the country compared to other developed and leading developing countries, as presented in Figure 4 (UGC, Higher Education at a Glance 2013) and

[12] http://www.elsevier.com/about/press-releases/science-and-technology/elsevier-analysis-reveals-brain-gain-rather-than-brain-drain-for-india
[13] http://sactopm.gov.in/Science%20in%20India%20-%20Book.pdf
[14] http://www.dst.gov.in/whats_new/press-release13/pib_04-03-2013_1.htm

Figure 5 (Bound and Thornton, 2012). This is not in line with the growing enrolments in Science as UGC's annual data for 2011-2012 show (registering a 21 percent increase over the figure in 2010-11). This is primarily due to the fact that science and technology as a career option is not very attractive to young graduates – even to those graduating from our premier higher education institutions such as the Indian Institutes of Technology as many pursue unrelated career paths.

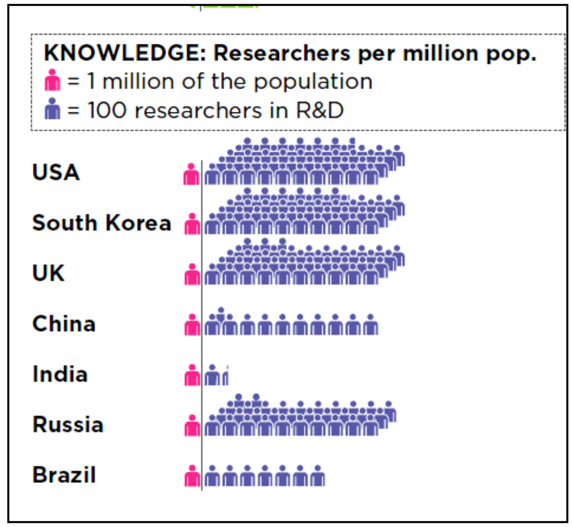

Figure 5: Researchers/Population
Source: Bound and Thornton, 2012

Despite a large tertiary student population, India has not been able to increase the number of PhDs in science and engineering significantly (from 54 per 10 million in 1983 to 70 in 2004). China, which lagged India until a decade ago, now has 174 science and engineering PhDs per 10 million population.

The SAC-PM Vision Document (2010), that lays the roadmap for India to become the 'global leader in science' calls for a target of producing 30,000 per year, by 2025, as against 8286 PhDs (S&T, agriculture, medicine, veterinary) produced in 2013, Figure 6 (UGC Higher Education at a Glance, 2013). This will require an exponential shift in the quality of existing institutions that produce PhDs. It will also involve sustained efforts to attract the best talent to science. An obvious numerical challenge that comes into play here is that not enough post-graduate seats are allotted to facilitate the smooth transition from under-graduate to PhD programmes. This will be discussed in detail in the next section.

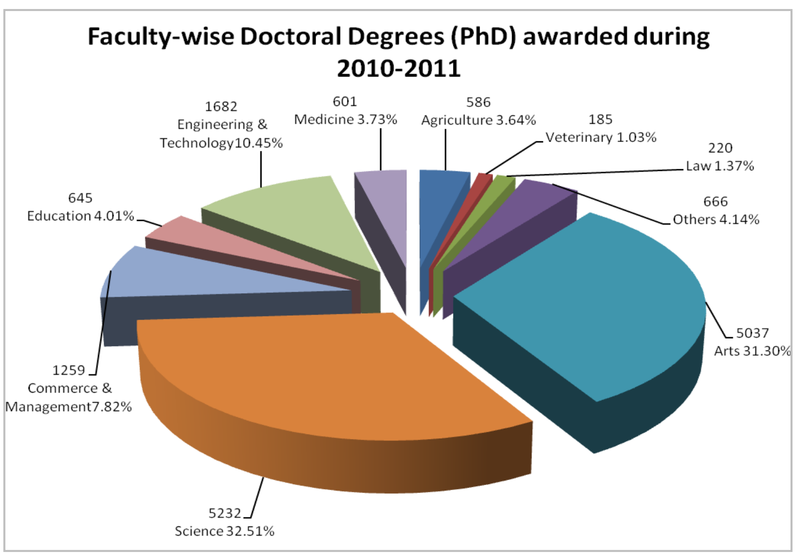

Figure 6: Faculty-wise Doctoral Degrees (PhD) awarded during 2010-'11
Source: UGC, Higher Education at a Glance 2013

Our discussion above helps us infer why when it comes to high technology balance of trade India represents only 1.2 percent and 0.4 percent of the world's high technology imports and exports, respectively (see Table 2).

Countries	% of world's High-Tech Imports (2007)	% of world's High-Tech Exports (2007)
India	1.2	0.4
China	13.2	18
Japan	4.5	7
Israel	0.3	0.2
EU	30.2	33.1
US	14.4	13.2

Table 2: World's High-tech Imports and Exports (2007)

Source: UNESCO Science Report 2010

Policy Framework: India's science and technology policies though lofty in content have been weak in implementation. The examples of China, South Korea, USA and Israel, presented here and elsewhere in the report reveal how strengthening the competitiveness in universities with good leadership, adequate resources and a commitment to continuous improvement, should form the very bedrock of a nation's S&T policy.

The **Scientific Policy Resolution of 1958**, the first policy document outlining India's vision for science, and largely attributed to Prime Minister Jawaharlal Nehru and Homi Bhabha, aimed "to promote, foster, cultivate and sustain science and scientific research" and at the "intense cultivation of science on a large scale" and its application to meet a country's requirements. The **Technology Policy Statement (TPS) of 1983** focused on attaining technological competence and self-sufficiency.

Two decades later, the new Science and Technology Policy introduced in 2003, called for integrating programmes of the socio-economic sectors with the national R&D system and the creation of a national innovation system. The **Science, Technology and Innovation (STI) Policy 2013**, coming as it does in the **"Decade of Innovation"** (2010-20), aims to focus on Science & Technology led innovations by linking contributions of scientific research and innovation system with the inclusive economic growth agenda. So, in summation, we concur with the vision of the SAC-PM, that in order to set up an Indian Agenda for Leadership in Science-led Innovation, the essential elements of a powerful national ecosystem "comprise physical, intellectual and cultural constructs. Beyond mere research labs, it includes idea incubators, technology parks, a conducive intellectual property rights regime, balanced regulatory systems, strategically designed standards, academics who believe in not just 'publish or perish', but 'patent, publish and prosper', some scientists, who have the passion to become technopreneurs, potent inventor investor engagement, 'adventure capital, and passionate innovation leaders"*(SAC-PM 2013, p.191).*

1.1. Challenges ahead

The preceding introduction brings us to the basic premise of this report **'Whither Science Education in Indian Colleges?'** - which is, to attract good talent to science, we need to turn the tide of popular perception that studying science is an unwise career choice, by bringing about urgent reforms in science education, particularly at the tertiary level.

Enhancing quantity and quality of human resources: STIP 2013, like its predecessor, recognizes the importance of improving both the quality and quantity of our scientific manpower; and expects the total number of R&D personnel to increase by at least 66 percent. But STIP does not spell out how these growth targets were arrived at and the specific schemes for incentivising science and engineering as a career option to young graduates (Mani, 2013).

To build depth into the knowledge base in Science, Technology and Innovation, we need institutions that ingrain the culture of excellence and lifelong learning in their students. With rapid changes in technology there is a rising demand for a strong set of foundation skills upon which further learning builds. The skills and knowledge that individuals bring to their jobs, to further studies, and to our society, play an important role in determining our economic success and our overall quality of life.

In this context, the World Economic Forum's Global Competitiveness Index (2013) commenting on the abysmal participation of women in the workforce in India claims that, with a ratio women-to-men of 0.36:1 , "India has the lowest percentage of working women outside the Arab world". Science is often viewed as a masculine subject (Kelly 1985). In a country like India, socially dictated stereotypical roles of women in society; lack of female role models in science; lack of career options after pursuing science; could be some of the reasons for the under-participation of women in science related fields. Attracting women to science is one area that needs to be paid serious heed to. Interestingly, studies have shown that the gender gap in the choice of S&T subjects both at school and tertiary level has been seen in developed countries as well.

Eliminating the bottleneck at the post-graduation level

If we are to increase our core S&T human resource, inclusiveness needs to be coupled with better access. The SAC-PM Document 2013 calls for at least an increase of 3 lakh PG scientists per year by 2025. In order to achieve the goal of producing 30,000 PhDs per year, by 2025, we need to ensure a fairly large and consistent supply of postgraduates into the education system. But a quick glance at some universities tells us that this is not the case. For example, the University of Mumbai, Department of Physics Brochure 2012-13 states that there are a total of 316 students enrolled in University for the MSc programme of which 64 students are enrolled in the Department opting for the eight areas of specialisation offered at the second year, while the remaining 143 seats are allotted in the Mumbai University's affiliated colleges and other sub-centres, which constitute a total of 19 institutes. About 20 seats are available for M.Sc. by research programme.

The brochure further states that the demand ratio of the M.Sc. programme is high; about 450 applications are received for the 240 available seats (p. 21). Thus the seats for the post graduate programmes are barely meeting half of the student demands to pursue higher studies.[15]

The University of Delhi in its annual bulletin[16] for admission to postgraduate science courses (2013-14), announced the number of seats that students have to compete for in order to get into the Masters programme of their choice, which can be seen in Table 3. To be eligible for these, one has to either qualify through their B.Sc merit, for which 50% of the above seats are allotted; or through a M.Sc entrance exam, for which the remaining seats are allotted. The overall low number of post-graduate seats in particular specialisations within a core subject allotted by the University can constrict the entry of prospective students, who are genuinely interested in science[17].

Subject		*No. of Seats Available*	*Duration of Course*
(i) Physics		294	2 years
(ii) Chemistry		278	2 years
(iii) Botany		78	2 years
(iv) Zoology		92	2 Years
(v) Anthropology		46	2 years
(vi) Geology		32	2 years
(vii) Environmental Studies	M.A.	23	2 years
	M.Sc.	23	2 years

Table 3: Subject wise seats allotted by the University.

Source: Bulletin of information for admission to post-graduate science courses, 2013-14. University of Delhi

Strengthening India's science and technology capabilities by strengthening the university system: As we have seen, R&D is globally done in three types of organisations – universities, government-owned labs and company labs -- the first two are influenced a great deal by government policies and investment. Global experience tells us that out of the two, except for some focussed R&D related to defence, space etc., the efficiency and effectiveness of the university is higher. Most research output comes from universities, and most of the Nobel Prize winners work in academia (Malik & Jalote, 2011). This report therefore makes a strong case for strengthening R&D capabilities of Indian universities.

Historically our universities have been teaching-only places. TIFR was established in 1945 and soon after independence, specialised autonomous research institutes and laboratories like the CSIR, DST, DAE, DRDO, DOS, DBT, etc. set up their own autonomous research centres in specified areas. This led to the unintended but disastrous consequence of separation of university students from research.

[15] In 2013, the University of Mumbai issued a circular which informed prospective students, the number of seats allotted for MSc in each subject. The number of seats in the MSc level entry are 161 seats (botany), 162 seats (zoology), 173 seats (microbiology), 90 seats (biochemistry) and 316 seats (physics). The demand for admission varies subject to subject. See http://www.mu.ac.in/sa/sa_tybscsem6cbsgs.pdf and http://www.mu.ac.in/science/physics/Brochure_Physics5.pdf

[16] http://www.du.ac.in/fileadmin/DU/students/Pdf/admissions/2013/PG/07052013_facultyofscience_info-bulletin.pdf

[17] The case Kashmir University: More aspirants, fewer seats. http://www.greaterkashmir.com/news/2013/Apr/3/more-aspirants-fewer-seats-30.asp

While research progressively took a back seat in universities, teaching became noticeably absent from the research institutions. Only in recent years has this anomaly sought to be corrected, with poor results so far.

Besides the direct R&D output, universities also produce PhDs and Masters degree holders who form the main resource pool for corporate and government research centres; as well as teachers at schools, colleges and universities themselves. Unless this university “nucleus” does well, it is not possible to build either a strong R&D ecosystem in a nation or a large enough reservoir of top-notch teachers.

Promoting research in academia: Experts say that there is no policy support in STIP 2013 to promote R&D activities and “research intensity” in the higher education sector namely, in our universities and colleges (Krishna 2013). Although education has been a concurrent subject since 1976 the bulk of the colleges and universities in India, well over 90% of the enrollment, are under the purview of the State governments. The latter have been spending very little of their Gross State Domestic Product (GSDP) on education and much less so on higher education. The only mechanism through which universities and affiliated colleges can receive financial assistance from the Central government is if they come under the 12B classification of the UGC Act 1956.[18] However, less than a third of these institutions are eligible to receive any kind of financial assistance from the UGC, and much less so for research.

In Japan, South Korea, Singapore and China, leading universities are not only moving towards infusing entrepreneurial culture but are embedded in national innovation strategies as frontiers of innovation (Krishna, 2013). India too must move towards making our universities the centre of innovation and new knowledge creation. The newly announced Rashtriya Uchchatar Shiksha Abhiyan (RUSA) mission is a step to strengthen state universities.

Building competitive spirit: Unlike in the United States, there is little competition for getting research funding – the number of academic institutions with the capability to truly conduct R&D is so small that there is no pressure to achieve excellence in order to get government funds. Now, with the emergence of corporate research labs in India, there is at least an emergence of external competition for recruiting faculty in some sectors. Competition among universities can be strengthened considerably by having independent and rigorous evaluation on a regular basis using a proper framework that compares Indian universities and their departments with each other, as well as with universities across the world. These evaluations (as in the case of National Science Foundation (NSF) discussed in the subsequent pages) will generate a sense of competition between the universities and, if done in a proper manner, can also provide universities with some directions for improvement. Establishing a centre like the Centre for Measuring University Performance in the US can be a major step in this direction, say Jitendra Malik and Pankaj Jalote (2011) in their essay, ‘Ideate and Innovate: R&D ecosystem in India must be fixed’.

[18] http://www.ugc.ac.in/page/UGC-ACT-1956.aspx

Autonomy: It should be clear that supporting a competitive spirit among universities will necessarily require them to have much more than academic autonomy – they also need administrative and financial autonomy. An organisation cannot compete if it does not have basic tools like the ability to decide compensation, incentive structure, etc. Here, the argument that since the government provides most of the funding, it must exercise control does not hold. Universities in the US, Europe, Singapore, Australia etc. are heavily funded by the government, yet they are very autonomous in deciding their salaries, their incentives and administrative processes.

Strengthening institute-industry linkages: Autonomy will empower Indian universities to develop linkages with industry partners, explore opportunities for funding outside the government grant channels. At the same time, if businesses have to sustain global competitiveness in the knowledge era, they have to be supported with quality human resources and modern tools. The role of institute-industry – also, institute-agriculture – linkage in designing courses, developing skills and imparting training in the regional and rural innovation systems needs to be emphasised.

There is a critical need for forging links between formal R&D institutions and the needs and demands of firms in Small and Medium Enterprises (SMEs) and clusters, which provide far more employment and wealth creation opportunities than large enterprises. There is no large funding agency like the NSF in USA that can step up R&D investments. Nor is there a model to tap into multiple sources of grass roots innovation and make them commercially viable. A networked model involving academic and industry institutions can match India's need to strengthen bottom-up entrepreneurship. If these technologies and capabilities are harnessed, India's economic competitiveness would certainly get a boost.

Strengthening institute-agriculture linkages: One of the biggest weaknesses in science education in India is the weak or, rather, non-existent linkage between educational institutions in rural areas and the agriculture-based socio-economic environment around them. There are two assumptions or dogmas at work here. Firstly, many in the government and education sector believe that rural students have nothing to learn from, or about, agriculture. Secondly, Indian agriculture does not need any inputs of scientific knowledge and research, beyond what is provided in specialised agriculture colleges, Krishi Vigyan Kendras (KVKs) and government programmes.

A third dogma has entered the mindset of urban-based policy-makers and intelligentsia – they believe that since the share of agriculture in India's GDP is steadily falling (now standing at around 18 percent), there is no need to pay much attention to it.

Sociologically too, a new thinking is rapidly gaining ground in rural India. Educated youth in villages coming from agricultural families do not want to pursue agriculture as their career, considering it to be inferior to jobs in towns and cities. This, in addition to other factors contributing to the crisis in Indian agriculture, has led to large-scale migration of people from villages to urban centres. It does not take much reflection to realise the disastrous consequences of this trend.

To strengthen institute-industry and institute-agriculture research linkage, a dedicated institution could advise universities on procedural reforms. This would also encourage industry investments in university R&D whereby some of their research could be outsourced to universities without fear of intellectual property theft.

Strengthening leadership and global competitiveness: India needs a young, informed and motivated leadership in charge of policy-making and at all levels in the science, technology and innovation value chain. The Global Competitiveness Index 2013 lists low enrolment rates in higher education, lack of technological readiness (the capacity to fully leverage technologies – especially ICT in daily activities and production processes for increased efficiency) and the dismally low participation of women in the workforce, as being constraining factors in India's competitiveness[19].

The access to higher education can be measured in term of Gross Enrolment Ratio (GER), which is a ratio of number of persons enrolled in higher education institutions to total population of the persons in age group of 18 to 23 years. The estimate based on Selected Education Statistic indicates that the access to higher education measured in term of gross enrolment ratio increased from 0.7 percent in 1950/51 to 1.4 percent in 1960-61. By 2006/7 the GER increased to about 11 percent (UGC, 2008). India's Gross Enrolment Ratio (GER) in higher education, currently stands at 19 percent, which is far below the ratio in developed and several emerging countries (MHRD & CII, 2013).

To enhance the quality of Human Resource in Science and Technology we believe that the foundation will have to be laid from school education itself. And our study shows that this is where India flounders. To be an innovative society, much more than enhanced R&D budgets are needed. Building an open society, one that appreciates diversity and one that attracts creativity and openness are strategies that will encourage innovation (Weber and Duderstadt, 2010).

Popularising science at the grassroots: India has a strong tradition of voluntary organisations working at the grassroots for the popularisation of science and science education – to develop scientific temper, entrepreneurial spirit and transforming lives in the process. These efforts need to be replicated nationwide for maximum impact. The comment by Dr. Shirley Tilghman (former President of Princeton University) that science education should instil a comprehension of the scientific matters even in those that will not pursue a scientific career holds good for our society too. In *"full appreciation of the transformative role of S&T in daily life"*, she states, *"Without well-informed policy makers and a discriminating public, scientific progress will be slowed down or misdirected, to everyone's detriment. From embryonic stem cells to evolution, from climate change to manned space exploration, scientists and non-scientists have found themselves at cross purposes, partly because the scientific community can be frustratingly insular, but largely because we [USA], as a nation, have failed to acquire a general understanding of and respect for the foundational principles of scientific research."* (Tilghman, 2010)

To conclude, reforms in science education in India are imperative. In this context, it is important to revisit the timeless wisdom of Jamsetji Nusserwanji Tata (1839-1904), doyen of Indian industry: There is one kind of charity common enough among us… It is that patchwork philanthropy which clothes the ragged, feeds the poor, and heals the sick. I am far from decrying the noble spirit which seeks to

[19] The Global Competitiveness Index, 2013 (World Economic Forum) - http://www3.weforum.org/docs/GCR2013-14/GCR_CountryHighlights_2013-2014.pdf

help a poor or suffering fellow being… [However] what advances a nation or a community is not so much to prop up its weakest and most helpless members, but to lift up the best and the most gifted, so as to make them of the greatest service to the country[20].

In 1909, when the House of the Tatas established the Research Institute of Science for India (now known as the Indian Institute of Science) in Bangalore, Jamsetji Nusserwanji Tata's vision of students with "ascetic" spirit who will "devote their lives to the cultivation of sciences – natural and humanistic" was realised. This institute stands as a proud beacon of scientific achievement today and is rated among the best universities in the world. What India needs is several such institutes that can nurture and unleash the innovative spirit among millions of young Indians for service to the country and indeed to humanity.

[20] The quotable Jamsetji Tata - http://www.tata.in/aboutus/articles/inside.aspx?artid=1U2QamAhqtA=

2. REFORMS IN SCIENCE EDUCATION: CASE STUDIES

"Educationists should build the capacities of the spirit of inquiry, creativity, entrepreneurial and moral leadership among students and become their role model."

Dr. A. P. J. Abdul Kalam

Over the last fifty years, many countries have been reforming their science education system[21]. These reforms not only targeted primary, secondary and tertiary education, but also addressed the entire ecosystem of science and technology, with varying degrees of success. But in a competitive environment which is driven by sound policies, such reforms have invariably yielded good results.

In spite of a natural cross-fertilisation of ideas (e.g. due to academic debate, globalisation, and information circulation through the internet), each country has embarked on its own reform process. (Rajput & Srivastava, 2001; Atkin & Black, 2006). Many countries have been engaged in national debates to reform science education and how it can be made more relevant to society in general.

Reforms in science education all over the world have been propelled by several factors (Guo, 2007):

- Decline in the number of students pursuing basic science degrees;
- Wide gap between learning goals and learning outcomes;
- Adoption of constructivist learning theories in science learning;
- The debate on "science for citizenship";
- The results from cross-national studies on students learning (TIMSS PISA, and SAS);
- Globalisation and liberalisation;
- Advances in science, technology especially information and communication technologies (ICT);
- Concerns over sustainability of the growth process.

2.1. The case of United States of America

For several years the United States has been at the forefront of scientific advancement. Its universities occupy the top ranks in any academic ranking[22]. In 1944, President F.D. Roosevelt stated that when "ability, and not the circumstance of family fortune, determines who shall receive higher education in science, then we shall be assured of constantly improving quality at every level of scientific activity". In July 1945, in a report to the President, titled 'Science the Endless Frontier', Vannevar Bush, Director of the Office of Scientific Research and Development, outlined what is

[21] E.g. China, Japan, South-Korea and Singapore, United Kingdom, Netherlands, Germany, France, Finland, Sweden, ,Norway, United States of America, Australia and New Zealand.

[22] Times Higher Education Ranking 2012-13 http://www.timeshighereducation.co.uk/world-university-rankings/2012-13/world-ranking/region/north-america

considered the road map that helped the United States take the lead in scientific progress – a lead which they have maintained ever since. Linking scientific progress to cultural progress Vannevar Bush stated that, *"Scientific progress is one essential key to our security as a nation, to our better health, to more jobs, to a higher standard of living, and to our cultural progress"*[23].

In 1950, the National Science Foundation (NSF) was established.

National Science Foundation (NSF)
What made USA the world leader in S&T

An independent federal agency created by the US Congress in 1950 "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…"

Funding: Annual budget of about $7.0 billion (FY 2012)

Funds approximately 20 percent of all federally supported basic research conducted by America's colleges and universities.

Major source of federal backing in many fields such as mathematics, computer science and the social sciences

Grants and cooperative agreements to more than 2,000 colleges, universities, K-12 school systems, businesses, informal science organisations and other research organisations

Currently about 11,000 new awards per year, with an average duration of three years

Evaluation of proposals: Nearly every proposal is evaluated by a minimum of three independent reviewers consisting of scientists, engineers and educators who do not work at NSF – a national pool of 50,000 experts in each field evaluates proposals

Support for Science education: From pre-K through graduate school and beyond the research funded by NSF is thoroughly integrated with education to help ensure the availability of plenty of skilled people to work in new and emerging scientific, engineering and technological fields, and plenty of capable teachers to educate the next generation.

About 200,000 scientists, engineers, educators and students at universities, laboratories and field sites all over the United States and throughout the world are supported.

The latest report on science funding in the United States, (Kennedy 2012) shows that the private industry spent $247.4 billion, or 62 percent of total R&D spending, while the federal government spent $124.4 billion, accounting for 31 percent of the nation's spending on R&D. Universities and colleges get nearly 58 percent of its R&D funds from federal funding.

[23] Science – The Endless Frontier - http://www.nsf.gov/od/lpa/nsf50/vbush1945.htm

Excellence and competitiveness is pursued in the American university system at three levels:

- Competition to get good students – all the main universities vie for them;
- Competition to attract the best faculty – universities go out of their way to get good faculty and vigorously compete even with corporate research labs (and, they often win this competition);
- Strong competition for research funding.

In spite of the leadership status of USA in Science and Technology in 2009, President Obama with a view to stay ahead as a top-ranking nation in science, technology, engineering, and mathematics (STEM) initiated the 'Educate to Innovate' programme providing billions in additional federal funding for STEM education programs across the country.[24]

In 2008, in India, the Science and Engineering Research Board (SERB), described as an Indian counterpart of the NSF, was set up as a statutory body for supporting basic research in emerging areas of science & engineering. Contrary to the claims to "liberate science from bureaucracy[25]", this body now functions under the bureaucratic control of the Department of Science and Technology.

2.2. The case of South Korea

The pillar of Korea's Science and Technology policy was creation of state-led research and educational capacity centred on state-run research institutes, and in-house research and development efforts by large industrial conglomerates called *chaebol* (Campbell, 2012).

Korea has been investing heavily in education. In 2008 it spent nearly 20 percent of its budget on education — 11 percent was for tertiary education and 88 percent for K-12 education. 3.37 percent of GDP was devoted to R&D, almost a full percent increase over 1998.

To further support "Big Science," the Korean government enacted the ambitious 577 Program:

- to raise R&D investment to five percent of GDP;
- to focus on seven major technological areas along with traditional industrial automotive, electronics, and military technologies were included the space program, nuclear development, and "convergence technology" (nanotech and robotics);
- to achieve global Top Seven status in terms of scientific citations and international patent applications.

The Long-Term Vision for Science and Technology Development, put forward in 2010:

- shifting the locus of the "national innovation system" from government to private sector;
- enhancing the efficiency of R&D investments;

[24] http://www.whitehouse.gov/issues/education/k-12/educate-innovate
[25] India as a Global Leader in Science, 2010, pg 32, http://www.dst.gov.in/Vision_Document.pdf

- upgrading R&D to world standards;
- science and technology promotion in different regions of the country and not just in the Seoul region;
- and trying to "harvest the opportunities presented by new technologies.

(Source: Campbell, 2012)

2.3. Reforms in India

The Indian government is devising more opportunities for capacity expansion, making fullest use of Indian scientific talent to work in Indian academia & scientific research institutions and laboratories. In 2013, the Department of Biotechnology started three major new science clusters in the National Capital Region (NCR), Mohali and Bangalore. These institutions have expanded their institutional and other programs to provide excellent opportunities and working environment to attract the best Indian scientists working abroad to work in India.

Since 2000, several new initiatives have been undertaken or are being explored:

i. Establishment of a large number of centres of excellence: Indian Institutes of Science Education and Research (IISERs in Kolkata, Pune, Mohali, Bhopal and Thiruvananthapuram), National Institute of Science Education and Research (NISER in Bhubaneswar), National Institutes of Pharmaceutical Education and Research (NIPER in Mohali)

ii. Establishment of specialised centres of research and education in space technology, defence technology, translational research, biotechnology and stem cell biology.

iii. Expansion of existing institutes such as IITs, initiating undergraduate education programs at IISc and initiating study programmes at TIFR.

In the book Science in India (SAC-PM 2013) in the chapter titled 'Major Recommendations & Accomplishments of the SAC-PM (2004 - 2013)' the following has been listed as accomplishments:

- Establishing the Ministry of Earth Sciences and Earth Commission
- Establishing of the Department of Health Education and Research
- Setting up the new research funding agency, Science & Engineering Research Board

Important institutional structures in life sciences and biotechnology have been established:

- Biotechnology Regulatory Authority of India (BRAI)
- National Institute of Animal Biotechnology, Hyderabad
- Regional Centre of Biotechnology in collaboration with UNESCO, Hyderabad
- Translational Health Science Technology Institute, Gurgaon
- National Institute of Agriculture Biotechnology, Mohali

- National Institute of Biomedical Genomics, Kolkata
- Institute for Stem Cell Research and Regenerative Medicine, Bengaluru

Supercomputing roadmap: The Planning Commission has drawn a National Supercomputing Roadmap for the 12th Plan (2012-2017) period covering several aspects of supercomputing namely Architecture, Supercomputing Grid resting on the National Knowledge Network and the Million Core Cloud Supercomputer[26].

In recent months, the government has introduced several new schemes with public private partnerships to increase spending on R&D to help the quick commercialisation of basic and academic research into products of direct relevance to the industry. To encourage entrepreneurship and innovation in new scientific concepts and technologies, the Government has lined up several programmes ranging from venture-capital funding to the development of incubation centres.

The specific targets of the Science, Technology and Innovation (STI) Policy 2013 underscore the need for creating a world class scientific talent pool:

- Positioning India among the top five global scientific powers by 2020 (by increasing the share of global scientific publications from 3.5 percent to over 7 percent and quadrupling the number of papers in top 1 percent journals from the current levels);
- Increasing the number of Full Time Equivalent (FTE) of R&D personnel in India by at least 66 percent of the present strength in 5 years;

And, above all, raising Gross Expenditure in Research and Development (GERD) to 2 percent from the present 1 percent of the GDP in this decade with a public investment of Rs. 1,20,430 crore ($ 18.5 Billion) and an approximately eight-fold increase in the engagement of the private sector into R&D in PPP mode. Indian industry needs to come forward to contribute about 50 per cent of the increase in R&D spending.

The buzzword at the centenary of the **Indian Science Congress**[27] **(ISC)** held in Kolkata in January 2013 was "Science, Technology and Innovation for the people" with a call to bring forward the youth to work for the promotion of science for India's future. Some of the key recommendations were[28]:

- Attract talent and develop human resource for science, technology and innovation;
- Prepare a youthful leadership pipeline in the science sector to shape the future of India;
- Re-adjust governance processes in the universities for rejuvenation of research in academia;

[26] DST Press release March 14, 2013

[27] The Indian Science Congress Association (ISCA) owes its origin to two British Chemists, Professor J. L. Simonsen and Professor P.S. MacMahon who envisioned that scientific research in India might be stimulated if an annual meeting of research workers somewhat on the lines of the British Association for the Advancement of Science could be arranged. http://www.sciencecongress.nic.in

[28] http://dst.gov.in/whats_new/press-release13/pib_07-01-2013_1.htm

- Invest special efforts to develop the requisite human resources critical to the investments planned in mega-science projects;
- Link the discovery processes in science to the problem solving responsibilities of the research and development activities by creating institutions to convert scientific discoveries into commercial products and processes, quickly;
- Enhance public outreach of science by creating a new breed of scientists who are also effective communicators, (in the language understood by people) to bridge the growing perception-gap on numerous aspects of science and technology which impact people directly;
- Invest in new modes of pursuing scientific research to meet the country's challenges for food and nutrition, energy and environment, water and sanitation, affordable health care;
- Strengthen Public and Private Partnerships in R & D sector.

2.3.1. Schemes to attract talent to science

Scheme	Details	Financials
Innovation in Scientific Pursuit for Inspired Research (INSPIRE)	Scheme for Early Attraction of Talent for Science (SEATS) - Winter and summer camps for top 1% performers in schools: Age group of 10-15.	Rs 5,000 for a duration of 5 years.
	Scholarship for Higher Education (SHE) - 10,000 scholarships to students undertaking Bachelors and Masters level education in natural sciences: Age group of 17-22.	Rs 0.8 lakh per year
	Assured Opportunity for Research Careers (AORC) - fellowship in basic and applied sciences, including engineering and medicine. Age group of 22-32.	--
	INSPIRE Faculty scheme - for pursuing post-doctoral research to faculty. The scheme provides a provision for a maximum of 1,000 awards per year. Age group of 27-32.	Fellowship equivalent to the scale of an Assistant Professor of an IIT and a Research Grant of Rs 7 lakhs per year for 5 years.
Ramunajan Fellowship, Science and Engineering Research Board (SERB), Government of India	To attract brilliant scientists and engineers from all over the world to take up scientific research positions in any of the scientific institutions and universities in the country	Fellowship: Rs.75,000 per month and Research grant: Rs.5 lakhs per annum
Department of Biotechnology (DBT)	Welcome-DBT India Alliance is a three-tier fellowship programme on biomedical research at the post-doctoral level	Pounds Sterling 8 million per year has been committed by both parties for a period of ten years
	Ramalingaswamy Re-entry Fellowship for Indian scientists who are working in overseas institutions/ universities and would like to return to India to pursue their research interests	Allowance of Rs.75,000 per month; Research/ contingency grant of Rs.10 lakhs for first year, Rs.7.5 lakhs for 2nd year and Rs. 5 lakhs third year
	Young Investigator Meet (YIM) is organised every year in India and overseas to create awareness amongst scientists working in overseas laboratories of the various job opportunities available in India.	--
Council of Scientific and Industrial Research (CSIR)	Scientists/ technologists of Indian origin (STIOs), who are given a designation of "Outstanding Scientists, STIO" are appointed at an identified CSIR laboratory so as to nurture a research field in their area of expertise.	Pay scale of Rs 37,400-67,000 in Pay Band-4 with, Grade pay of Rs 12,000
Kishore Vaigyanik Protsahan Yojana	Scheme run by Indian Institute of Science, Bangalore also aims to attract talents for science	Fellowships for KVPY Fellows doing B.Sc will be Rs 5,000 per month;for M.Sc students Rs 7,000 per month

Table 4: Schemes to attract talent in science

There are various schemes to spot and encourage young talent, to attract overseas Indians to work in S&T and to attract resources as faculty. Some of these are presented in Table 4.

Apart from this, Promotion of University Research and Scientific Excellence (PURSE) is a programme under Research & Development head of the Department of Science and Technology introduced in 2008 to incentivise university publications. Consolidation of University Research, Innovation and Excellence (CURIE) has been designed to strengthen R&D in all six women-only universities in the country (DST Annual Report 2010-2011).

The Homi Bhabha Centre for Science Education, Mumbai, is the nodal centre of the country for Olympiad programmes[29] which aims at promoting excellence in science and mathematics among pre-university students. The Mathematics Olympiad is conducted under the aegis of the National Board of Higher Mathematics (NBHM). Since August 2008, a new integrated National Steering Committee has been overseeing the entire activity (in Physics, Chemistry, Biology, Astronomy and the Junior Science departments) comprising the Indian Association of Physics Teachers (IAPT) and the Homi Bhabha Centre for Science Education (HBCSE), financially supported by the Government of India.

The National Innovation Foundation (NIF), an autonomous body of the Department of Science and Technology, Government of India, has been actively engaged in promoting creativity and innovation in India. One of its main aims is to recognize and reward grassroots technological innovators and traditional knowledge experts. The NIF hosts the National Biennial Awards where the President of India felicitates the grassroots innovators of our country. Prof. Anil Gupta of IIM-Ahmedabad, a pioneer in the promotion of grassroots innovation in the country is its Executive Vice Chairperson.

2.4. Private efforts at innovation in science education

Science education forms the very basis on which a nation's scientific temper, spirit of enquiry, innovativeness and problem solving approach rests. In the Indian context, in view of the diversity of faiths and cultures, issues such as communication for science awareness for the masses through Indian languages, study of science and faith, creating a symbiotic relationship between traditional and modern medicinal systems, assume significance.

India has a strong tradition of voluntary organisations working at the grass roots for the popularisation of science and science education. In the post-Independence period, SS Kalbag, Anil Sadgopal, Vinod Raina, Vivek Monteiro and several others left their promising mainstream careers to dedicate their lives to the task of strengthening science among people. Their life work extends beyond the sphere of science education – producing low-cost educational tools, creating a scientific temper, entrepreneurial spirit and transforming lives in the process[30].

The following pages provide examples of movements that are replete with lessons for strengthening the educational system and popularising science among the public. Since the 1970s, the People's Science Movement (PSM) has been an umbrella body of grassroots organisations of various

[29] HBCSE – Olympiad official website - http://olympiads.hbcse.tifr.res.in/
[30] http://www.indianexpress.com/news/education-visionary/1174320/3

ideologies (Marxists, postmodernists, environmentalists, feminists, multiculturalists, social constructivists), working in a much decentralised manner, on diverse issues, to reclaim science to work for people. The group also works for changing people's mind-set of fatalism and belief in superstition to rational thinking. Many groups, therefore, work to popularise science in a number of areas such as health, education, nutrition, housing, environment, communication, agriculture, and sanitation, so people can also enjoy benefits of science. Some of them are:

- All India Anti-Imperialist Forum
- All India People's Science Network
- Patriotic People for Science and Technology (PPST)
- Vigyan Shiksha Kendra
- Bharat Gyan Vigyan Samiti
- Bhopal Gas Affected Working Women's Union
- Chilka Bachao Andolan, Chipko Movement, Narmada Bachao Andolan
- Friends of Rural Society
- Kishore Bharati
- Eklavya
- Total Literacy Campaign
- Kerala Sastra Sahitya Parishad (KSSP)
- Movement in India for Nuclear Disarmament (MIND)
- National Fish Workers Forum
- Maharashtra Andhashraddha Nirmoolan Samiti (MANS) or Maharashtra Blind faith Eradication Committee
- Samskrita Bharati

Eklavya, founded by the late Dr Vinod Raina, also played a key role in the movement. It engaged in policy research and advocacy, involving all stakeholders in the process – policymakers, scientific institutions and the general public – to move towards the democratisation of science and technology at all levels, so that the people at large could become informed participants in decision-making on issues that crucially impacted their lives (Varma, 2001). Dr Raina joined his other PSM colleagues in taking this experience international and in catalysing the nascent World Forum for Science and Democracy.

Vigyan Ashram

In 1983, Dr Shrinath Kalbag, PhD in Food Technology from the University of Illinois, Chicago, quit a lucrative career in a multinational, to start his dream project, Vigyan Ashram, at a village called Pabal in Pune district to promote non-formal education for rural youths, especially school drop-outs. Over the years, the ashram has made a significant contribution in the field of vocational education and reforming the education system. Its focus is on education for technological innovation that is needed to create livelihood opportunities for the masses.

Vigyan Ashram Fab Lab:

Fab Lab, a brain child of Dr. Neil Gershenfeld (Director, Center of Bits and Atoms, Massachusetts Institute of Technology), is a distributed international network of scientific researchers and community inventors to define, conduct and apply new discoveries and inventions to benefit both research and local communities. In 2002, the first Fab Lab outside MIT was set up at Vigyan Ashram. Some of the projects taken up at Vigyan Ashram's Fab Lab are i) Human power based lighting solution ii) LED lights iii) Egg incubator iv) Agri sensors etc. Vigyan Ashram Fab Lab also hosts several innovative students projects (Diploma-Graduate-Masters) every year.

Chai and Why

TIFR's (Tata Institute of Fundamental Research) Science Popularisation and Public Outreach Committee develops programmes for teachers of science to communicate to the community. One of its initiatives is Chai and Why.

This initiative:

- Reaches out especially to less privileged students in rural and urban areas and explains to them the scientific work being done at TIFR.
- Inspires students to pursue a career in basic sciences.
- Informs the public about the latest trends and developments in scientific research.
- Conveys the importance of exciting new developments in science and technology.
- Provides authentic information to journalists who write about science.

Source: http://www.tifr.res.in/~outreach/outreach/outreachchai.html

Hoshangabad Science Teaching Programme (HSTP) and Eklavya

In 1972, the government of Madhya Pradesh and two NGOs -- Friends Rural Centre (FRC), Rasulia, and Kishore Bharati (KB) – undertook a pilot project in 16 middle schools to study the feasibility of introducing a 'discovery'-based approach to learning science in rural schools in place of the traditional textbook-centred rote learning to help build an analytical and enquiring culture among children. This project came to be known as the Hoshangabad Science Teaching Programme (HSTP). Prof Anil Sadgopal, a student of molecular biology from California Institute of Technology (Caltech), Pasadena, was the man behind this mission. Prof Anil Sadgopal has dedicated his life for a just and equitable society. With the state granting administrative backing and academic freedom to experiment with books, kit, curricula, teacher training and examinations, the HSTP was able to address innovation and quality improvement in science education holistically, focusing on all aspects of school functioning. The programme has also benefitted from the active involvement of young scientists, educators and research students from some of the leading academic and research institutions such as the All-India Science Teachers Association (Physics Study Group), Tata Institute of Fundamental Research (TIFR), Mumbai, University of Delhi, IITs, various universities and post-graduate colleges.

The UGC granted fellowships to faculty members from Delhi University and other academic institutions to participate in the programme at the field level. The Madhya Pradesh government also permitted its college science teachers to interact on a regular basis from 1975.

This synergy between the university, community and school science teachers in developing academically sound curricular materials for village schools was also a unique feature of the programme. In 1982, out of this programme was born Eklavya, an NGO for educational research, to identify and create mechanisms and structures for translating micro-level innovations into macro-level action programmes. Late Vinod Raina was the founder. Today the HSTP has evolved as a comprehensive model for implementing innovative science teaching in the mainstream education system at the upper primary stage: development of curriculum and text books; teacher training; academic support to schools; reforming examination and evaluation systems.

Source: http://www.livemint.com/Leisure/8pR1bqeZQYUl3wMlQ3jbYI/Freedom-to-study--Anil-Sadgopal.html
http://www.eklavya.in/index.php?option=com_content&task=category&sectionid=12&id=52&Itemid=74

These efforts need to be feted, strengthened and replicated.

2.5. Science education in schools

Science education in primary and secondary schools lays the basic foundations of students' scientific knowledge. A detailed analysis of the state of science education in Indian primary and secondary schools is out of the scope of this report. Nevertheless, given its importance for science education at the college level, a brief sketch of the state of science education in Indian schools is provided here.

For the last five decades, science and mathematics education have been part of compulsory general education during the first ten years of schooling (Rajput & Srivastava in Poisson, 2000). The importance given to science and mathematics education has been a constant in Indian policy on education. However, there is a wide gap between desired and achieved outcomes. The quality of science education, as that in other subject matters, is affected by four main factors: 1) curriculum overload; 2) poor focus on conceptual development, promotion of curiosity and free enquiry; 3) inadequate teacher training; and 4) inadequate and faulty assessment of learning outcomes.

The science curriculum content is needlessly excessive, often decontextualised and outdated. The preparation of pre-service and in-service teachers is inadequate with significant cross national asymmetries. The assessment methodologies are woefully inadequate, promoting rote instead of meaningful learning. These problems naturally permeate into tertiary education, as will be observed in the following sections. (For reforms introduced until 2001 in science education at primary and secondary level see review by Rajput and Srivastava in Poisson, 2000).

Although central and state governments have been engaged in solving these problems, and some improvements have been made, there is a crying need for fast paced and large scale improvements. This is an uphill task given the serious problems of corruption and lack of accountability faced at central and state government institutions, along with the geographic and demographic dimensions of the country.

India's PISA scores in science literacy

The multi-national Programme for International Student Assessment (PISA) from the Organisation for Economic Co-operation and Development (OECD) is a longitudinal study on the reading, mathematical and scientific literacy of 15-year-olds, across OECD and some non-OECD countries (PISA website). PISA aims to inform governments' policy to improve educational outcomes. PISA surveys are designed to assess the application of knowledge in everyday contexts, and to avoid rote problem solving.

PISA (Walker, 2011) defines scientific literacy as: *"An individual's scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence-based conclusions about science related issues, understanding of the characteristic features of science as a form of human knowledge and enquiry, awareness of how science and technology shape our material, intellectual, and cultural environments, and willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen." (p. 4)*

In 2009, the two Indian states of Tamil Nadu and Himachal Pradesh participated in the PISA study.

Both Tamil Nadu and Himachal Pradesh scored well below the OECD average (501 points), with 348 and 325 points respectively. However these results should be taken as mere indicators as the students sampling of both Indian states did not meet PISA standards of sampling. China, Finland and Singapore, were the countries that scored higher; with 575/545, 554 and 542 points respectively (ACER PISA Report, 2011). PISA assessment classifies students' scientific literacy in six proficiency levels with level 1 being the lowest and 6 being the highest. The results for India are presented in Table 4 (Walker, 2011).

	< Level 1	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Boys							
Himachal Pradesh	51.8 %	34.6%	10.4%	2.3 %	0.5%	Nil	Nil
Tamil Nadu	46.8 %	40.3%	10.6%	1.8%	0.5%	Nil	Nil
Girls							
Himachal Pradesh	63.6%	27.5%	6.9%	1.6%	0.4%	Nil	Nil
Tamil Nadu	41.0%	41.3%	14.6%	2.8%	0.4%	Nil	Nil

Table 5: Results of Indian students' scientific literacy in six proficiency levels
Source: Walker, 2011

All students scored below level 5, with a clear majority of students (both genders) scoring below level 2. In general the level of scientific literacy in both states is comparable. From the results, there is no apparent gender difference in terms of scientific literacy between girls and boys.

"Level 1, students have such a limited scientific knowledge that it can only be applied to a few, familiar situations. They can present scientific explanations that are obvious and follow explicitly from given evidence."

"At Level 2, students have adequate scientific knowledge to provide possible explanations in familiar contexts or draw conclusions based on simple investigations. They are capable of direct reasoning and making literal interpretations of the results of scientific inquiry or technological problem solving."(ACER PISA Report, 2011)

Results suggest that nearly half of the students in both Indian states do not have the scientific knowledge required to make sense of familiar situations, nor can they present obvious scientific explanations. The remaining can do so only for a few familiar contexts. From the results students' capacity to engage with higher order reasoning also seems to be limited. Could this be a result of the inadequacy of the designed questions, given the Indian context? It is unlikely, as questions are designed to take into account cultural heterogeneity. These results seem to suggest that science education needs to be improved at both primary and secondary levels, to support students in developing their scientific literacy. Moreover, both Tamil Nadu and Himachal Pradesh are among the top ranking states in literacy. One cannot but wonder what would be the PISA results in states which are lower in the literacy ranking.

3. ORF Mumbai's study: State of Science Education In Indian Colleges

"Creativity is contagious. Pass it on."

Albert Einstein

3.1. ORF Mumbai's study of science education in Indian colleges

The Observer Research Foundation Mumbai conducted primary research in 2011 to probe the state of science education in Indian colleges, focussing primarily on urban centres like Mumbai, Chennai and Delhi. Some colleges in Maharashtra, outside Mumbai, were also selected. Secondary research involved review of existing policy documents and scientific literature. The main objectives of this study were to provide a holistic portrait of the state of science education; identify the bottlenecks in the education system; and to provide a roadmap for revamping science education.

Extensive survey of committee reports and review of literature helped set the context of this study. This study was undertaken through several structured and semi-structured interviews with the main stakeholders, namely, principals, vice-principals, teachers, research scholars, students, educators, placement officers from science colleges in Mumbai, New Delhi and Chennai, members from the industry, potential employers and researchers. The interviews were recorded and transcribed verbatim for subsequent analysis. The profile of the colleges and universities participating in this study is presented in Annexure 1. The interview responses were organised by category and analysed qualitatively.

For this project, ORF Mumbai collaborated with Dr. Sanjay Deshmukh (Head of Department, Life Sciences, University of Mumbai) and Ms. Adithi Muralidhar (M.Sc. Zoology, University of Mumbai,

Figure 7: Study sites of ORF Mumbai's project

who has subsequently joined our organisation).

This was followed by a consultative roundtable conference[31] on 10th July, 2011 which saw participation of members from all stakeholder groups. The roundtable was organised for two reasons: 1) To present the preliminary findings of the study on the status of science education in Indian colleges and 2) To consult with various stakeholder groups regarding solutions. Several important points were voiced during the course of the roundtable which have been incorporated in the report.

The roundtable was chaired by renowned academician, Prof. Ashok Jhunjhunwala, IIT-Madras. Some of the issues raised in this report were reiterated by Prof. Ashok Jhunjhunwala:

- The current system has not delivered and the changes made have not been good enough.
- In communication theory, the half life of new knowledge is 3 to 4 years. By graduation fifty percent of the knowledge gained is gone. Hence we need to teach how to learn. Learning is a lifelong process and with our own knowledge the same contents evolve, because we understand them from different angles.
- Autonomy is very important; the teacher needs to have the freedom to decide how to go about what needs to be taught. We have made attempts to address the quantity and equity problem, but not the quality problems.
- There is a need to devise new and more sustainable models for financing education. Perhaps Government, instead of banks, can start giving educational loans to students with zero percent interest. Perhaps when one repays the loan back, that amount can be made tax-deductable.
- There is also a poor delivery on the potential of ICT in Education. We have not experimented sufficiently with pedagogy in ICT based education.
- We need to teach students knowledge relevant to today's society, both local and global. They need to be taught concepts that can be applicable locally.
- There is no emphasis on the importance of liberal arts.
- Lastly, we have failed to take leadership in the education system (this pertains specially to senior scientists from top institutions).

The results presented in this section provide a holistic perspective of the state of science education viewed through the lens of some of the best colleges in India in science streams. The problems and obstacles faced by these colleges are expected to be amplified in many other colleges in tier-two urban areas and rural areas.

When asked to identify the most critical challenges in science education, participants in the survey frequently cited the following points:

- Poor quality of teaching;

[31] For list of roundtable participants, refer Annexure 2

- Inadequate infrastructure and facilities;
- Inadequate funding;
- Low employability and limited career options for students;

To this must be added the lack of good science teachers at primary and secondary levels of education; and the lack of inspiring leadership at institutional or national level that conveys a vision for science, science education, research, and their critical role in India's all-round development. These points are a mere tip of the iceberg, revealing deep dysfunctionalities in our educational system as well as in our society.

3.2. Poor quality of teaching

There is a serious shortage of 3.8 lakh of faculty in higher education and this is likely to grow to 13 lakhs in a decade's time. This leads to the highly inappropriate practice of ad-hoc hiring of teachers[32].

The poor quality of teaching is a consequence of the following factors:

- Lack of training for teachers in pedagogy and delivery mechanisms and lack of mastery over content;
- Excessive focus on examinations;
- Lack of accountability of teachers and educational institutions to educational outcomes;
- Low motivational levels of faculty;
- Outdated, compartmentalised and disconnected curricula;
- Poor quality of educational materials;
- Poor recruitment policies for teaching positions.

The roundtable also highlighted some issues faced by the teachers regarding the non-payment of arrears of the Sixth-Pay Commission salaries, which further increased resistance from teachers' unions, in terms of workload and work hours.

Lack of training for teachers in pedagogy and delivery mechanisms and lack of mastery over content

Teachers in most of the institutions do not undergo training programs on pedagogy and delivery mechanisms. As a consequence many fail to actively engage with their students. Some of the students interviewed made reference to a great heterogeneity in the quality of teaching. While some teachers actively engage their students in classroom discussions and are receptive to questions, others resort to a lecture mode limiting discussion and Q&A sessions. For some students this is a reflection of a certain degree of diffidence on the part of the teacher regarding his / her mastery over

[32] Report of the Task Force on Faculty Shortage and the Design of Performance Appraisal System, July 2011, http://www.ugc.ac.in/pdfnews/6675510_taskforce.pdf

what he / she is teaching. *"Many teachers do not understand the core concepts of their areas of expertise; this is a serious limitation to the transmission of knowledge and leads to rote teaching."*[33]

> *"The quality of these refresher courses varies widely. Hardly one third of the teachers are actually interested and committed, the rest attend these courses for the sake of a promotion."*
> Prof P. Riyazuddin,
> University of Madras

The University Grants Commission (UGC) and the Academic Staff Colleges of universities provide refresher courses for teachers (UGC website). Three training sessions (of 21 days) are compulsory for career progression. Nevertheless, these courses are focussed exclusively on specific subjects, with no reference to education technology and pedagogy. *"The quality of these refresher courses varies widely. Hardly one third of the teachers are actually interested and committed, the rest attend these courses for the sake of a promotion"*[34]. The reactions to these courses vary widely: some teachers find them extremely useful while others feel that they are not learning anything new. *"The refresher courses are not well designed; they need to be far more creative and innovative. These courses are not helping teachers in their present form. We need to get out of the routine."*[35]

Modern technology can in many ways help in the teaching-learning process. Substantial research backs up the potential of using Information and Communication Technology (ICT) in the classrooms, as a means of effective communication between teachers and students. In what concerns the use of ICT, some of the colleges participating in this study have only a few classrooms equipped with laptops, projectors and Internet access, as well as fully equipped computer rooms. While some of their faculty members are actively using the audio-visual and digital media in the classroom, many are still strangers to technology. Sophia College, Mumbai organises internal workshops on informatics to foster the teachers' use of ICT in education.

Excessive focus on examinations

As Professor C.N.R. Rao, Chairman of the SAC-PM, stated, "India does not have an educational system, it has instead an examination system"[36]. The excessive focus on centralised examinations has reduced the Indian educational system to a mechanism of unimaginative delivery and reproduction of content. This has also affected the morale of teachers, as they have to teach only for the examination purpose (Chandran-Wadia, Correia, Joseph, Vishwanathan, 2011).

> *"India does not have an educational system, it has instead an examination system."*
> Bharat Ratna Dr. C.N.R. Rao

The educational system fosters rote learning which consists of memorising facts without properly integrating them in a knowledge structure: *"Teachers are the product of a*

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[33] From an interview with Professor K.V. V. Murthy from IIT Gandhinagar.
[34] From an interview with a Professor Riyazuddin from University of Madras.
[35] From an interview with Dr. C. Natarajan from HBCSE.
[36] Talk given at the EDGE Conference in New Delhi, 2011

defective educational system oriented towards memorisation rather than comprehension; this leads to a closed loop of rote teaching – rote learning."[37] Rote learning impairs the development of critical thinking skills, a crucial skill for the study of any discipline, in any academic stream.

Under the affiliated college system, teachers are not involved in their students' assessment. This does prevent feedback in the teaching-learning process – either from the teacher to the student or from the student to the teacher. This in turn impacts the teacher's accountability to outcomes.

> *"Competitive exams are killing the taste for science in the country. Almost five lakh students start from a very tender age to prepare for exams like JEE, attending coaching classes, doing nothing but studying science and this gives people a wrong impression of science."*
>
> **Prof Kannan Moudgalya, IIT Bombay**

In order to tackle this serious problem of evaluation, several universities are in the process of adopting the more accepted methods of assessment and evaluation like Continuous Comprehensive Evaluation (CCE) and Choice Based Credit System (CBCS). Even prestigious universities like the University of Mumbai have introduced the Choice Based Credit and Grading system only as recently 2010-11. Dr. Rajan Welukar, Vice Chancellor of University of Mumbai states: *"It is hardly a debatable matter now as to whether a University or any other higher education provider for that matter should adopt a Credit Based System or not. We must recognize the fact that every student has the right to learn what he wants to learn and from wherever he wants to learn. The system of assigning Credits to each course or module undertaken and allowing flexibility of course combinations both within an institution as well as across institutions respects this 'Autonomy' of the student."*[38] He further added that *"The Credit Based System which provides a clear accounting of the student's efforts and learning load, places the student at the centre stage of all academic transactions and facilitates the bringing of all the education providers on a common platform. In this sense, the system is ideally suited for respecting the independence of the student and promoting the much required 'Learner Mobility'. It is imperative; therefore, that every forward looking institution takes a bold step in setting up an appropriate Credit Based System and the University of Mumbai cannot afford to lag behind."*

Lack of accountability of teachers and educational institutions to educational outcomes

The lack of accountability of teachers and educational institutions is yet another key dimension that contributes to poor quality in education. The absence of formal checks and balances and adequate sanction mechanisms combined with teacher's low motivational levels (to be discussed below) has led many teachers to neglect their responsibilities. This lack of accountability of academic and non-

[37] From an interview with Professor K.V. V. Murthy from IIT Gandhi Nagar

[38] Manual of Choice Based Credit Systems (CBCS) and Grading, University of Mumbai, 2011, Page 4

academic staff, as well as of educational institutions has been a serious problem over the past few decades.

One of the most striking effects of the lack of accountability is teachers' absenteeism, *"Some teachers consider their college duties as part-time jobs, and often engage in tuition/coaching classes or other remunerative activities."*[39] This problem is faced by many affiliated colleges and university departments. Educational institutions are not empowered to prevent absenteeism. As an example, Delhi University has been struggling with this problem for quite some time and attempted to introduce in 2009 a biometric system of attendance for teachers. Teachers unions went on strike for more than a month and the university could not enforce it and was forced to withdraw. However, many conscientious teachers do feel that the actions of a few discredit their profession, and that accountability mechanisms should be implemented to fight malpractices.

Another striking example of lack of accountability is the fact that many students do not have access to their corrected papers/exams (which can be attributed to a shortage in administrative staff and/or to the work load of faculty). Teachers do not – and often cannot – provide a detailed correction of the paper/exam to students[40]. This poses a serious pedagogical problem, as students get only very limited feedback on their performance, based exclusively on their marks. Students have therefore no information whatsoever on the themes that were well understood and on those that require further study. This will naturally affect their quality of learning.

There is effectively no standard national level monitoring in terms of quality for most of the educational institutions. The coverage of accreditation through the National Assessment and Accreditation Council (NAAC) and program accreditation through the National Board of Accreditation (NBA) is still small and mainly optional. Less than one-third (179 out of 574) eligible universities and one-seventh (5,156 out of 35,539) of eligible colleges have been accredited so far. Private universities and private colleges have shown little enthusiasm for accreditation. (MHRD, 2013)

The NAAC accreditation is based on the submission of a self-study report prepared by the educational institution, followed by an on-site visit and a recommendation of assessment from a peer team, to be validated by the NAAC Executive Council. The assessment is made on the following criteria: curricular aspects; teaching and evaluation; research and consultancy; infrastructure; learning resources; student support and progression; governance and leadership and innovative practices[41]. The accreditation system has revealed several deficiencies that need to be addressed: the system is focussed on inputs rather than outcomes; there is no continuous accreditation; accreditation of courses and institutions are not concomitant; stakeholders have no voice; there are no penalties; only to mention a few (Planning Commission Sub-Committee, 2009, p. 15). The report has issued in 2009 a set of recommendations to address these issues and revamp the accreditation system[42].

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[39] From the interviews with Professor P. Riyazuddin from the University of Madras and Professor H. P. Singh Proctor of Delhi University.

[40] Information provided by students from Ruia College, Mumbai.

[41] NAAC - http://www.naac.gov.in/

[42] http://planningcommission.gov.in/reports/genrep/skilldev/sub_accrd.pdf

In 2010, a Bill on National Accreditation Regulatory Authority for Higher Education was submitted to the Lok Sabha that called for compulsory accreditation of all Higher Educational Institutions. Programmes will also have to be accredited for academic quality. The Bill in its present form poses some potential obstacles to an effective accreditation system: While it seeks to end NAAC's monopoly, only government controlled agencies are allowed to accredit, ruling out the possibility of healthy competition with private agencies. Accreditation agencies are expected to guide institutes in improving their quality if this is not the case the agency will be penalised which might give rise to conflict of interest, and partial evaluation (Sanyal, 2010). According to the Mandatory Assessment and Accreditation of Higher Educational Institutions Regulations, 2012, any institution of higher learning, other than those in technical institutions, will have to compulsorily get accreditation by an accrediting agency, after passing out of two batches or six years, whichever is earlier in accordance with the norms and methodology prescribed by such agency or the commission. Those institutes who do not comply with this can be penalised.[43]

NAAC has enforced the existence of an Internal Quality Assessment Cell (IQAC) in every accredited college. This encourages the institution to design an internal assessment system to monitor the quality of its academic and non-academic activities, as well as the performance of their academic and non-academic staff. Several colleges produce annual IQAC reports, available on-line at the college's website. As part of their IQA systems, many colleges have implemented student feedback surveys. The surveys are usually collected and used for faculty improvement programmes. There is a plan to introduce performance-based funding for universities and colleges through the proposed state higher education councils.[44] This is likely to ensure a spirit of competition among institutions and improve the efficiency of funds usage.

Low motivational levels of faculty

Poor quality of teaching seems also to be correlated in some cases with teacher's low motivational levels.

How can a teacher be motivated when his / her professional dignity is being challenged?

Most teachers do not actively contribute to the design of the curriculum and of educational materials. They do not have a voice in student's assessment. Many of their students have very low motivational levels for learning (see student's difficulties sub-section, below). Teachers often face a lack of adequate infrastructure, and they are rarely exposed to workshops, as well as national and international conferences. Teachers have poor career advancement prospects. There are very few incentives for good performance. The system does not incentivise merit and there is no external motivation to excel. Teachers face high teaching workloads due to teacher shortage. Apart from the academic work, teachers are often burdened with administrative duties in schools and outside. This further contributes to the already heavy workload they have. The teacher to student ratio is adverse (again due to the shortage of teachers) which impacts the quality of their interaction with students.

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[43] UGC released Notice in Gazette of India, January 2013, http://www.ugc.ac.in/pdfnews/8541429_English.PDF
[44] Performance-based funding soon : UGC Vice-Chairman - http://www.thehindu.com/news/national/tamil-nadu/performancebased-funding-soon-ugc-vicechairman/article5096316.ece; September 5, 2013

Outdated, compartmentalised and disconnected curricula

Science curricula and syllabi are designed as highly compartmentalised subjects. These are often excessively theoretical leaving little room for application and experimentation. Curricula are typically revised every 15-20 years in government-run affiliated colleges, while in a few privately-run affiliated colleges this gap is reduced to less than five years. *"In many affiliated colleges teachers are not interested in designing new experiments, we still have the same old 50-year experiments running today."*[45]

There is an overall consensus among educators and teachers that curricula are frequently outdated. This is not surprising given the slow pace at which they are revised. Outside educational institutions there is a dynamic market-driven system that is in constant update, informed by the advances in technology and new research avenues. In Massachusetts Institute of Technology (MIT), United States, 25 percent of the postgraduate curricula are revised and changed every year. At undergraduate level, where fundamentals are typically introduced, it is to be expected that curricula revisions would take place after a couple of years.

The curricula and syllabi taught in colleges are framed by Boards of Study (BOS) of the university to which the college is affiliated. In the case of Mumbai University, at the undergraduate level, the University's vice-chancellor appoints the BOS members comprising: chairman (usually a professor cadre academician with proven and acknowledged academic track record in that same subject); two eminent academicians from the university and one external resource (e.g. an academician from another university or a representative from industry).

In contrast, in the case of institutions like St. Xavier's College in Mumbai, which has been conferred academic autonomy, the boards are headed by each head of department and three senior faculty and include representatives from the University of Mumbai, from industry and alumni. For a given subject, teachers will draft the curriculum to be presented to the respective BOS. *"Every department found that it was an energising activity to discuss the curriculum with the Board of Study. The boards in turn felt that they had received good input and feedback. It is a very healthy practice."*[46]

Science curricula appears to be, to a great extent, disconnected from reality. The dissociation between research, industry and teaching in Indian educational institutes has contributed to the alienation of curricula from the pressing challenges faced by industries and other sectors of the economy. Some of the students interviewed in this study have expressed their frustration for not having the opportunity to address real problems, as well as for the lack of opportunities to apply their knowledge.

Poor quality of educational materials

At undergraduate and postgraduate levels, students are expected to study using different reference books and on-line materials. Some teachers provide their personal notes. There are numerous textbooks in the market considered by many teachers as low quality educational material. Some

[45] From the interview with Professor H. P. Singh, Proctor of Delhi University.
[46] From the interview with Fr. Dr. F. Mascarenhas, St Xavier's College, Mumbai

students use the notes of their seniors as complementary educational material. The quality of these notes are often reasonable, given that students select the best, based on their own set of criteria – the senior students' attendance and exam performance. Some students cannot afford to buy reference books. There are usually one or two that document the core concepts of a given field and are therefore extremely useful to study, but their price is usually high. The availability of these books at the college library is not always guaranteed (e.g. one copy for more than 20 students), so many students opt for buying pirated versions or pirated translations into regional languages. This is a problem because they do not undergo a quality check. Naturally, these pirated editions are available in the market at significantly lower rates.

The Internet is a good source of high quality on-line educational material. While many colleges are equipped with computers, Internet access is not always guaranteed. This poses a problem for students who do not have a computer or Internet access at home.

Poor recruitment policies for teaching positions

Currently, the recruitment of teachers in colleges is carried out as per the UGC norms. A crucial criterion to be considered for a teaching position is one of the following: qualifying through either the Council of Scientific and Industrial Research and University Grants Commission (CSIR-UGC) or UGC National Eligibility Test (NET) or State Eligibility Test (SET) or possessing a doctoral degree[47]. The abysmally low pass percentage in UGC-NET exams has always been a matter of concern[48], questioning the quality of education received by potential teachers attempting the exam, as well as the format of the qualifying examination. There has also been a growing fear that qualified candidates are pursuing careers that are not related to science. But a recent study showed that though a significant section of the CSIR-NET fellowship awardees did not avail their scholarships, majority continued to pursue careers in science and research (Hasan, Khilnani & Luthra, 2013). Despite this, it is imperative that in order to attract candidates with the appropriate level of knowledge and aptitude for teaching, a thorough evaluation of the National Eligibility Test (NET) is required.

In addition, over the last 60 years, a policy of positive discrimination aimed at the reduction of social disparities has resulted in the reservation of 50 percent of the seats in educational institutions for students and faculty from SC/ST and OBC groups [49] (Viswanathan, 2011). These teachers also get automatic fast-track promotions. There are some concerns regarding this policy and how it compromises standards of teaching and learning, but opinions are divided in this regard. Sometimes the 'reserved' category faculty, who are recruited on diluted merit criteria[50], do not meet the required standards of quality. When merit is thus diluted, students (including those from reserved social categories) who study under such teachers are naturally at a disadvantage. Hence, this policy actually works to the detriment of students from disadvantaged classes.

[47] http://www.ugc.ac.in/oldpdf/regulations/revised_finalugcregulationfinal10.pdf
[48] http://www.thehindu.com/features/education/college-and-university/article2361922.ece
[49] 15 percent for Scheduled Castes (SC); 7.5 percent for Scheduled Tribes (ST) and 27.5 percent for Other Backward Classes (OBC)
[50] http://ugcnetonline.in/ugc_net_objective_mode.php

In terms of faculty, *"The shortage of qualified applicants for teaching positions from the reserved category, leave those vacancies unfilled. As a consequence, the teacher-student ratio increases and with it, the teachers' workload."*[51]

Faculty shortage and the increase in student enrolments have had a deleterious effect on teachers' workload. According to the latest data published by UGC[52], as many as 5,707 teaching posts out of the 15,573 sanctioned ones are lying vacant across the Central Universities – that is over one-third of the total sanctioned posts.

With the expansion of the education sector, there is pressure on the supply of faculty. Shortage of funds and other regulations compel colleges to hire teachers on contractual or, worse, 'Clock Hour' appointments. Their job conditions (e.g. salary, job security) are quite precarious and often exploitative. Recent pay revisions have failed to address the plight of a majority of these 'ad-hoc' teachers, whose remuneration is far less than those of permanent teachers for the same kind and amount of work.

According to several college principals there are high- and poor-performing students in both categories (general and reserved). Nevertheless, students from reserved categories tend initially to have more difficulties because of language barriers. Many were taught in regional languages and have difficulties with English (the language currently used for science teaching at undergraduate and postgraduate levels). Some students from the reserved categories also appear to have more difficulties with subjects that require mathematical skills. In Delhi University and Miranda House College, additional English courses have been introduced to address this problem. Educational materials such as books and notes have been translated into Hindi[53].

Additionally, there is a great diversity of ability among students in Indian classrooms. Students come from varied cultural backgrounds; have religious, linguistic and socio-economic differences, each of which can influence their learning outcomes. This heterogeneity forces teachers to adjust the level of their lectures to meet the needs of the poor-performing students. Standards are necessarily lowered in the first year courses. According to several principals, if well guided, these poor-performing students tend to pick up and meet higher standards. But this is not always the case and therefore provisions need to be made to ensure that under-performing students have the required support to improve, without hampering the quality of education delivered to other students.

In 2006, after the introduction of reservation for OBCs and in order to keep the number of seats of the general category unchanged, the government proposed the expansion of admissions capacity in all existing universities and colleges. Today, educational institutions like Delhi University (DU) and its affiliated colleges are struggling with an increased number of under-graduate and post-graduate students. Admissions went up without adequate planning: *"The increase in the number of seats was not accompanied by a proportional rise in faculty and infrastructure – 2,700 faculty had to be hired in the space of three years. This represents an increase of 25 percent (D.U. has 8500 faculty members),*

[51] From the interview with a Principle from a reputed science college in Mumbai.
[52] http://www.ugc.ac.in/pdfnews/0342004_vacant-position-CU-as-on-01-01-2014.pdf
[53] From an Interview with Dr. Pratibha Jolly, Principal of Miranda House College

posing a serious recruitment challenge due to the shortage of qualified faculty. Often open-category faculty seats cannot be filled unless the reserved ones are already filled. This compromises the quality of education."[54]

Nevertheless, our visits and interactions with faculty revealed that many teachers are actively engaged with their students and do their best to overcome several barriers, and deliver quality education. For students they are a source of inspiration. Many teachers go out of their way to ensure that their students have access to high quality educational material. An example of this is the Botany library at Ruia College, Mumbai, where teachers and students created a cooperative from their own financial resources to buy books and other educational materials[55].

All these factors can be summarised as a severe lack of recognition of the contributions of the teaching profession. This lack of recognition has undermined the teaching profession for many decades fostering *"a culture of doing the least possible. This frame of mind has been damaging education in India. Teachers do not have the freedom to take initiatives and innovate. It is not so much a problem of the quality of teachers, but rather their low motivational levels and lack of accountability."*[56] This scenario will only change with programmes and policies that aim to revamp the teaching profession.

Summing up, the high focus on examinations and mechanical content delivery; the poor quality of some teacher training and refresher programmes; weak pedagogy; the system's inability to pin accountability on the stakeholders; teachers' working conditions and their low motivational level, as well as flawed reservation policies have shaped the poor outcomes in science education in Indian colleges.

3.3. Inadequate infrastructure and facilities

Inadequate infrastructure

Infrastructure is a crucial physical support to the educational activity for it provides the physical environment where students and teachers work and interact. The lack of adequate infrastructure emerged as one of the main problems in attracting students to science education. The current state of infrastructure in colleges varies widely from college to college. Minority-run and women's colleges, and colleges managed by private trusts appeared to be better funded and better equipped than the rest. This could be a direct consequence of increased administrative and financial freedom combined with good management practices.

Contrary to expectations, even NAAC accredited 'A' grade colleges suffer from lack of infrastructure. With expansion and the creation of new courses, classrooms have been converted to laboratories; some of these laboratories do not follow the minimum safety standards (e.g. adequate ventilation, showers and fire extinguishers, large and non-obstructed exits, etc).

[54] From an interview with Professor H. P. Singh, Proctor of Delhi University

[55] From an interview with two students who are doing their 2nd year B.Sc., from Ruia College.

[56] From an interview with Fr. Dr. Mascarenhas from St. Xavier's College in Mumbai.

"In an A grade college, we had a Biotechnology laboratory with poor ventilation, and no personal protection equipment – no gloves or glasses. We buy our own lab coats. There is only one fire extinguisher in the ground floor. [57] If this is the case of colleges considered among the best, one cannot but wonder the state of infrastructure in other colleges.

The principal author of this report visited several laboratories and classrooms in different colleges in urban areas. In some of these colleges, infrastructure was old but generally well kept. Some of the classrooms were dark, poorly ventilated and dilapidated, creating an environment hardly pleasant or conducive to learning/teaching, while other colleges were better equipped.

Environmental psychology has extensively reported the impact of the surrounding environment on the capacity to focus and learn (e.g. Sommer & Olsen, 1980; Horne, 2004; Hunter, 2005).

Instrumentation

As regards instrumentation, colleges are equipped to a greater or lesser extent with the instruments required to conduct practicals. Nevertheless, when it comes to more sophisticated instrumentation (high cost and high maintenance), faculty and postgraduate students often resort to creating informal networks between colleges and other institutions. In such cases, postgraduate students may request formal permission to use instruments available in other colleges or research institutions against the payment of a certain fee.

The universities of Madras and Delhi have made available central instrumentation facilities free of charge to all their affiliated colleges. For example, the DU has recently opened a Rs 500 crore state-of-the-art centralised laboratory facility with 20 instruments. This platform is oversubscribed and postgraduate students from DU often have to wait 2-3 weeks to get permission to run their samples. DU is planning to open two more state-of-the-art instrumentation centres. Mumbai University does not have such a platform; each department is equipped with certain instruments that can be used by affiliated colleges on an informal basis on personal request. There is no regulation regarding the use of these instruments. These facilities are mainly used by teachers/researchers and postgraduate students. Researchers and students also use the paid services of private research laboratories to run their samples.

As mentioned above, apart from central instrumentation facilities, colleges have their own instruments to conduct practicals and research. The state of these instruments varies widely amongst colleges. In some cases students and faculty have reported that instruments are not in good working conditions (multimeters and spectro-photometers that give absurd readings; microscopes with defective optical system, to name a few). This was observed in government, private as well as minority-run institutions.

Apart from classrooms and laboratories, the state of libraries and study rooms also varies significantly from college to college. Some students mentioned the absence of a good and quiet environment conducive to study. In general, the private- and minority-run colleges visited in the context of this study, appear to have better infrastructure than the government-run colleges.

[57] From an interview with a student who is doing her final (third) year B.Sc. (confidentiality requested)

Recently, the UGC has been awarding substantial grants for infrastructure renewal and acquisition of instruments to all colleges identified as Colleges with Potential for Excellence (CPE). While this programme has had a positive impact in a few top colleges, many other colleges are still left with very little support from UGC, central and state governments[58].

3.4. Inadequate funding

The lack of adequate funding is a very serious obstacle to the quality of education. The debates on funding and financial autonomy have generated much controversy both in the political and public realms. There is an overriding fear that education will become a profiteering activity, which could lower its quality and become inadvertently a vehicle for socio-economic discrimination.

Principals and teachers interviewed for this study have identified the following obstacles to adequate funding:

- Low fee structure in colleges;
- Excessive bureaucratic control over funding and expenditure;
- Time-lag between the fund/grant awards and their actual availability for expenditure;
- Tight and irrational regulation that rules out alternate and innovative fund raising activities.

Low fee structure in colleges

The low fee structure which aims to provide equitable access to higher education does not even cover 20 percent of the expenditure of universities[59]. The problem is that 75 percent of the government subsidies for higher education are essentially used to pay faculty salaries and pensions leaving very little for the improvement and rejuvenation of educational infrastructure and general facilities.

Many colleges run self-financed courses where the fee structure is higher; ideally this would be a way to increase their own funds. Nevertheless, these fees are also regulated and often are merely enough to pay faculty on a contractual basis. The case of St. Xavier's College in Mumbai illustrates this very clearly: *"St. Xavier's was until last year (2010) running a M.Sc. programme in Biotechnology for an annual fee of Rs 23,000 per student. This course had a maximum of 20 students. Without any government funding, this does not even pay teachers' salaries, let alone the required consumables and maintenance of infrastructure. This year the fees were raised to Rs 43000, but this is still not sufficient."*[60] This is a matter of concern as St Xavier's is one of the best science colleges in Mumbai. If they are facing these difficulties one cannot but wonder about the difficulties faced by other colleges.

[58] There are other schemes as well, like, , Star College Schemes by DBT, http://www.dbtindia.nic.in/proposals/Areas/HRD/Star/star_colleges_in_life_sciences.htm

[59] National Knowledge Commission, Note on higher education, 29th November 2006

[60] From an interview with Fr. Dr. F. Mascarenhas, St Xavier's College.

At the same time, affordability is indeed an issue in rural and semi-rural colleges. *"In my college, 70 percent of the students (total of 1700) come from the extremely poor socio-economic background. In 2010, none of these students could afford to pay even the subsidised fee".*[61]

Excessive bureaucratic control over funding and expenditure

The allocation of funds and the over bureaucratisation of expenditure is another obstacle to the management of educational institutions: *"The allocation of government and UGC funds does not allow for flexibility in fund use especially in areas of pressing need."*[62]

Time lag between the fund awards and their actual availability for expenditure

Some faculty mentioned the time lag between the award of funds and their availability for immediate expenditure, as an example: *"The UGC sends funds in batches. Departments cannot predict the arrival of these disbursements, which creates a problem for the use of these funds, which usually come with tight deadlines, even if the funds come sooner or later."*[63]

Tightly regulated sector that rules out fund raising activities

It is a widely acknowledged fact that the central funding mechanism for higher educational institutions disproportionately favours the central universities despite the state universities bearing far heavier burden of student enrolments (Yashpal Committee Report, 2009). Besides, funding in state higher education is currently done on an ad-hoc basis, is poorly coordinated, plagued by excessive bureaucracy. Instead of receiving block grants from the states that facilitate better utilisation of funds, institutions at times receive item-wise allocations that make it cumbersome to use all the funds.

Well-equipped classrooms, laboratories, libraries and computer rooms are crucial to create a conducive environment to ensure high quality of education. Practicals and research laboratories require expensive consumables and instrumentation. The maintenance costs of laboratories are often covered by UGC grants. Computers and instrumentation are financed by other UGC grants. Instrumentation is also financed by grants from the Department of Science and Technology (DST), namely the Fund for Improvement of S&T Infrastructure in Higher Educational Institutions (FIST)[64].

The data from the Ministry of Statistics and Program Implementation on the nature of expenditure by state universities shows that only 10 percent of their total expenditure is spent on capital works. The major chunk of their expenditure goes towards salaries of academic staff.

The Yashpal Committee Report (2009) advises that:

- Complementary sources of funding will have to be found even for state funded universities;

[61] From an interview with a Principal (requested confidentiality) from a college in Maharashtra.
[62] Adapted from the interview with Dr. Srinavas, Principal of Presidency College. Chennai
[63] Adapted from the interview with Dr. R. D'Souza, Vice-Principal Science at Sophia's College, Mumbai
[64] For more details, visit http://www.fist-dst.org/

- Funding agencies must provide block grants against a plan and universities must be allowed to spend them according to their priorities, subject to the plan;
- Universities must be able to hire professional fundraisers and professional investors to attract funding from non-government sources;
- Universities must be freed from the constraints imposed by funding agencies to obtain approvals for every single post.

At present universities are penalised for raising resources from donors by the system of matching deductions from their grants-in-aid. The Rashtriya Uchchatar Shiksha Abhiyan (MHRD, 2013), a centrally sponsored mission to provide a new impetus to higher educational institutions at the state level, advocates normative and performance linked funding which would lead to better utilisation of public funds, increase transparency and accountability within the system and also improve the performance of universities. However, as stated by both the Yashpal Committee Report (2009) and RUSA (MHRD, 2013), state funding may not be enough for institutions to expand their infrastructure and progress towards excellence.

The list put forward in the report of the Central Advisory Board of Education (CABE) Committee On Autonomy of Higher Education Institutions, 2005, identified sources of funds such as fees (both special fee and tuition fee) to be collected from the students; creation of endowments; corpus funds to be generated; alumni be contacted for fund-raising, donations and setting up of funding agencies.

The revenue that is obtained from various sources may be utilised for purposes such as maintenance of infrastructure; travel grants for teachers to participate in conferences, seminars, etc; extra-curricular activities – sending students for participation in competitions; social and family welfare of teachers like meeting the medical expenses, educational expenses for their family; student welfare, such as scholarships to be offered to economically backward and meritorious students, medals to be instituted for toppers in academics, etc. (CABE Report, 2005)

Consideration for students' financial difficulties

Students from economically weak backgrounds face serious financial difficulties during their studies. Once the admission fees are paid, these students still have to ensure funds for transportation, daily meals and educational aids. In some cases students contribute financially to the family income and take up part-time employment. Often financial difficulties lead students to abandon their studies mid-way and search for jobs. Some are also forced to pursue other degree options (where the admission fees are lower)[65]. Teachers who were interviewed mentioned that some of these students are often exhausted due to their non-academic burdens and have little time to study. Their academic performance is therefore seriously affected. Few manage to reconcile both studies and part-time jobs. Scholarship programmes are mainly targeting exceptional talent. Average performing students do not have access to scholarships.

[65] E.g : A student (from Ruia College, Mumbai) interviewed said that with a Diploma in pharmacy, he was not able to get a job because he was not a graduate. Additionally, he was not able to pursue B. Pharm. due to his family's poor financial status. He is now enrolled in a B.Sc. programme.

The function of an educational institution is to offer need-based support to a student in his / her personal and academic development, ensuring that by the end of the study, the student has acquired a solid foundation and the required skills to become a good professional. In view of this, the education system needs to become more inclusive and students of average performance should also be given an opportunity to develop their talents.

The actual structure of student loans needs to be revised. In many cases the submission and approval processes take far too long and banks request collaterals to support the loan in case of default. According to some students, many families cannot offer collaterals. In some cases friends or acquaintances eligible for loans will ask for a percentage of the loan in return for their favour. In their present form student loans are not a real option for many students. So far there is no interaction between colleges and banks to establish a platform for student loans.

The UGC has an agreement with the Reserve Bank of India (RBI) and the Indian Banks' Association (IBA) to provide educational loans. There are loans up to Rs 7.5 lakh for studies in India. Loans below Rs 4 lakh do not require collaterals. These loans are to be paid in a period of 5-7 years, with grace period of 1 year after completion of studies.[66] The UGC has a Post-graduate Merit Scholarship program, for 1st rankers of B.Sc. degrees, of Rs 24,000 per year for two years, for pursuing M.Sc. degree (UGC website). The Ministry of Human Resources Development (MHRD) has two scholarship programmes for undergraduate studies (Rs 12,000 per year for 3 years) and postgraduate studies (Rs 24,000 per year for 2 years). This is a programme with 50 percent reservation for women. To be eligible for this scholarship, students must be at or above the cut-off of 80 percent in the Class XII Board exams.

3.5. Low employability and limited career options for students

> *"Students will follow basic science only if they feel it is relevant and needed for society. This feedback is given by the market (through employment opportunities) and by the way society values science education. Society does not have a perception of the need of a skilled workforce in the field of basic sciences capable of pushing India's socio-economic development forward."*
>
> Dr. Chitra Natarajan,
> Homi Bhabha Centre for Science Education, Mumbai

Employability is a theme that encompasses diverse dimensions. The youth unemployment rate in India is five times the rate of adults (10.3 percent versus 2.1 percent), indicating that the transition from school to working life is often difficult[67]. Add to this the perception that B.Sc. degrees are frequently perceived by society as the "poor cousins" of engineering and medical sciences[68]. The reason behind this is that basic science degrees hardly give access to high paying jobs. Pursuing basic sciences often requires substantial time and

[66] http://www.ugc.ac.in/page/Educational-Loan.aspx
[67] OECD India Brochure 2012- http://www.oecd.org/about/publishing/IndiaBrochure2012.pdf
[68] This was a point that was brought up even in the ORF Roundtable.

financial investment in M.Sc. and PhD programmes to actually get a job either as a teacher or as a researcher. The competition to apply for M.Sc. and PhD programmes at the few top research institutions is already very high. Therefore for most students, parents and society in general, there are very few remunerative options when pursuing science as a career. Owing to the greater affordability and access to "job securing" professional courses in urban centres like Mumbai, several colleges in our study reported a dip in the number of student enrolments in basic sciences. For example, some science departments at the Institute of Science, Mumbai, identified as a college with Potential for Excellence, have registered a decrease of nearly 50 percent in enrolment numbers when compared to a decade ago.

The poor conceptualisation, delivery and outcome of the 3-year undergraduate programmes in India are partially to blame for the poor employment prospects of science graduates. Hence, for many students, basic sciences are 2nd and 3rd choices, following a refused admission in engineering or medical sciences. These students are often less motivated or interested in acquiring knowledge in the basic sciences. The B.Sc. degree is often the minimum eligibility criterion -- a mere passport to jobs – and that too, in an unrelated field. Nevertheless, *"there are a few students who are passionate for basic sciences and research, and that in spite of difficulties wish to pursue a career in these fields. These constitute, nearly 10 percent of the students' batch in every course. They are very motivated and actively participate in classroom discussions"*[69].

The problem of the lack of interest towards basic sciences is a socio-cultural problem above all. *"Students will follow basic science only if they feel it is relevant and needed for society. This feedback is given by the market (through employment opportunities) and by the way society values science education. Society does not have a perception of the need of a skilled workforce in the field of basic sciences capable of pushing India's socio-economic development forward. "*[70]

Low employability of fresh pass-outs is a dramatic reality in not just in Science but all of the three- year undergraduate – Arts, Science and Commerce – streams. TeamLease is a staffing firm that claims that it only hires 5 percent of its job applicants. In 40 percent of the cases, the rejected applicants need more than a year of "repair" or "up-lift" to make them ready for a job in the areas of language abilities, practical and communication skills, confidence and work ethics[71].

Picture Courtesy: Gary Varvel (http://iamstem.ucdavis.edu/2013/07/29/college-majors-and-unemployment-georgetown/)

Many colleges have placement cells; these units establish a bridge between future employers

[69] From an interview with Dr. R. D'Souza, Vice-Principal Science at Sophia's College.
[70] From an interview with Dr. C. Natarajan from Homi Bhabha Centre for Science Education
[71] Private conversation with staffing agency

(industry/ research institutions) and their students. The placement cell organises on-campus interviews for students. *"B.Sc IT, Computer Science, Statistics are the most sought after...followed by Mathematics and Physics...Companies look for students with good communication skills, personality and good performance in group discussion and personal interview.... even the offers they get have poor pay"*, says Devi Prasad, placement officer with Jhunjhunwala College, Mumbai. According to some of the students interviewed, not all B.Sc. degrees are equally targeted for placement: *"Applied sciences like biotechnology or biochemistry are preferred; subjects such as botany or zoology are not even targeted. Very few students usually get jobs through the placement cell"*[72].

Many employers hire fresh graduates or postgraduates based entirely on their soft skills. Subject matter expertise appears to be of secondary importance. This is a reflection of the point discussed above on the dissociation of curricula and syllabi from the job and market needs. There is a serious disconnect between academia, industry and research institutions (public and private). The low employability of fresh graduates has led to the introduction of the 4-year degree course in Delhi University to achieve a better balance between theory and practice, for better scope in research-based studies intended to enhance the employment potential of students[73]. Students have the opportunity of studying informatics, languages, management, among others. High emphasis is given to the development of communication skills. Students have to present research papers, deliver a seminar lecture and organise workshops/conferences.

According to some of the students interviewed, their perception of future career opportunities before choosing their undergraduate programmes was very limited. Apart from personal interest that leads a few to do some job-market research, students are frequently uninformed about career options and tend to make their choices based on "mob mentality".

Many do not have any long term plans. Even during graduation some complain that very little proactive action is taken on the part of the college to increase the awareness levels of students and parents regarding their future career options. Nevertheless, some students have also mentioned the great support given by teachers to help them with long term career planning. There are a few colleges that have implemented a mentoring system where either a teacher is assigned to guide a few students (3-5) or where students choose their mentors. Teachers and students have been unanimous in affirming the benefits of a mentoring system.

[72] From an interview with students doing their 2nd year B.Sc. in Botany from a College in Mumbai (confidentiality requested)
[73] http://www.du.ac.in/fileadmin/DU/Events/APamphlet.pdf

4. REVAMPING SCIENCE EDUCATION: ADDRESSING THE CRITICAL BARRIERS

"Every great advance in science has issued from a new audacity of imagination."

John Dewey

There is a broad consensus that the education system in India needs to be reformed. Over the last 60 years many of the same old problems have been identified and many of the same old recommendations have been put forward. The lack of effective implementation of many of these recommendations has led to small incremental changes, and overall, to a few effective changes. Many agree that we need a disruptive and constructive change capable of revamping the whole system and of making it more effective and relevant to meet the present needs of society. While some of our recommendations echo those made by the National Knowledge Commission Report and Yashpal Committee reports, others carry the fresh voice of the main stakeholders: students, teachers, educators and employers. Here is a quick glance at the recommendations made by the National Knowledge Commission (NKC Report, 2008):

Issues	Recommendations
Poor quality and shortage of adequate infrastructure	Invest in upgrading and expanding existing infrastructure, promote sharing of resources
Poor working conditions and lack of recognition	Revitalize the teaching profession to attract and retain quality teachers
Poor pedagogy fostering unimaginative rote learning	Revamp teacher training
Courses are highly compartmentalised	Promote career flexibility: modular four year B.Sc. for integrated M. Sc and Ph.D
Curricula are overloaded with content, poor demonstration of applications and poor hands-on learning.	Reform curriculum content – increase research component
Examination system promotes memorisation instead of creative thinking and problem solving	Reform the examination system, promote continuous assessment
Science educational materials are mainly in English, and quality varies widely	Disseminate high quality science educational materials in regional languages
Limited career options: Teaching and Research; Financial unattractiveness and lack of social recognition	Re-brand and promote careers in basic sciences
Wide declining interest in sciences	Launch massive outreach science programs targeting students and parents
Poor industry participation in Science Education	Encourage industry participation in science education

Table 6: Recommendations made by National Knowledge Commission
Source: NKC Report, 2008

A quick glance at the recommendations of the report of 'The Committee to Advise on Renovation and Rejuvenation of Higher Education' (Yashpal Committee 2009):

Issues	Recommendations
Compartmentalisation of disciplines and subjects – fragmentation of knowledge	Promote interdisciplinary environments – Each university should cover sciences, humanities and arts Design curricula to allow interdisciplinary crossing between subjects
Divide between teaching and research	Promote interaction and exchange programmes between teachers and researchers
Poor pedagogic quality	Improve the quality of academic staff refresher courses: focus more on communication and assessment skills
Shortage of good teachers	Improve working conditions to attract and retain good teachers
Lack of adequate funding	Create more scholarships programmes and special loans for students Change regulations to promote philanthropy and allow block grants.
Poor governance – under-management	Introduce programmes in education management and separate academic administration from general administration
Lack of academic and administrative freedom	Grant academic and administrative autonomy to educational institutions
Multiplicity of regulatory systems	Create a single National Commission for Higher Education and Research (NCHER)

Table 7: 'The Committee to Advise on Renovation and Rejuvenation of Higher Education' Report
Source: Yashpal Committee 2009

4.1. Strengthening the university system

The governance system in higher education has not kept pace with the massive expansion of colleges – from 700 in 1950 to over 30,000 colleges in 2012[74]. As a consequence of disproportionate affiliation (too many colleges under one university) the administrative burden of universities has grown and the quality of education has suffered. Table 8 presents some examples of Indian universities that have too many affiliated colleges.

University	Number of Colleges
Osmania University, Hyderabad, Andhra Pradesh	901
Pune University, Pune, Maharashtra	811
Bangalore University, Karnataka	687
Mumbai University, Mumbai, Maharashtra	711
Andhra University, Andhra Pradesh	614

Table 8: Universities with the largest number of affiliated colleges
Source: University Grants Commission, 2012

Education in Indian colleges is in a curious state of deadlock; universities are incapable of uplifting their affiliated colleges and colleges do not have the power to lift themselves up. The result is that standards remain low and the appetite for excellence is being completely destroyed. If this tendency is to be reversed, two possible solutions emerge from this scenario: 1) the breakup of universities to a more manageable size and/or 2) increasing independence of colleges from their affiliating universities.

The first solution would imply that University of Mumbai, for example, would be divided into four independent universities, each with its affiliated colleges. Given that this solution would require significant restructuring, a more detailed discussion of this subject is out of the scope of this report.

The second solution concerns autonomy of colleges, an idea that has been under discussion for the last 40 years, and has generated much debate ever since. To better understand the debate on autonomy, a brief historical perspective is presented below (Rao, 2008):

- In 1968 the Kothari Commission underlined the structural weaknesses of the affiliating system, its impact on education with the growing expansion of educational institutions, and the need to bring in autonomy to colleges in a phased manner.
- In 1978, 12 colleges in Tamil Nadu were awarded academic autonomy.
- In 1984, there were 21 autonomous colleges across 5 states.

[74] http://www.ugc.ac.in/oldpdf/pub/report/12.pdf

- In 1986 the Programme of Action for the National Policy on Education recommended that 500 colleges should be made autonomous during the Seventh Five Year Plan period (1985-1990).
- In 1990, the Ramamurthy Committee revised the NPE-1986 and re-endorsed the need to increase the number of autonomous colleges.
- In 2003 the UGC issued a circular to all universities on "Autonomous Colleges: Criteria, Guidelines and Patterns of Assistance", highlighting the need to bring some flexibility in higher education by introducing academic autonomy, and blaming the rigidity of the system for the previous failures in attempting to implement autonomy.
- In 2005, the Central Advisory Board of Education committee has issued a set of recommendations to both universities and colleges regarding autonomy, and the preparatory steps for its successful implementation (for details see CABE report, 2005).

As of January 2014, only 455 out of a total of 30,000 plus colleges were autonomous[75]. In spite of 40 years of recommending autonomy, only a very small percentage (approximately 1.2 percent) of colleges are autonomous. This scenario may be explained by the scepticism and fear that autonomy has been evoking. For many teachers and non-academic staff, autonomy is often a synonym of financial difficulties, more exacting work conditions, nepotism, loss of credibility (caused by no longer being affiliated to a reputed university) and resulting lower educational standards. These fears, in our view have built a powerful lobby against autonomy.

Thirty years of experience of academic autonomy in Tamil Nadu has shown that autonomous colleges reached higher quality standards of education (Rao, 2008). Colleges with academic and administrative freedom are doing far better and have more credibility among the education community and the society in general. Some success indicators are: participative decision-making; implementation of quality assurance programmes to ensure the quality of education and the accountability of both faculty and administrators to the process; fully operational working partnerships with other institutions, industries and private companies (Rao, 2008). The results show therefore that fears of low educational standards and lack of accountability are unjustified in the context of autonomy.

> *"There is a deep intellectual reason for academic autonomy and that is to teach the right things so that students learn how to learn."*
>
> Prof. Shobo Bhattacharya,
> TIFR, Mumbai

Ramnarain Ruia College of Mumbai was recently conferred the 'College of Excellence' status by the UGC (February, 2014). It has become the first and only college in the country to have been accorded this status. In this regard, Principal Dr Suhas Pednekar commented that *"Research at the undergraduate level will benefit greatly from this recognition. While academic autonomy is our next aim,*

[75] http://www.ugc.ac.in/oldpdf/colleges/autonomous_colleges-list.pdf

UGC should take the initiative of conferring autonomy themselves on colleges they feel have the potential to sustain the autonomy."[76] Dr Pednekar was thus indicating the inclinations of some of Mumbai's best colleges towards autonomy.

The revamping of the College of Engineering in Pune after being granted autonomy provides a very interesting case study advocating for the benefits of autonomy[77]. Here is an extract from the study titled "How a historical engineering college is getting transformed through autonomy": *"The saga of change began since the grant of autonomy in 2004 and through the active involvement and support of eminent Board of Governors of the institute, several measures were undertaken at the academic, administrative and managerial levels, making a complete turn-around and the college is now close to achieving excellence like IITs."*[78]

Some of the principals and teachers participating in our study were from autonomous colleges. All were unanimous in declaring that there was an increase in the workload, but that the decision towards autonomy was absolutely necessary to improve and maintain quality. Participation in decision making and freedom were compensatory factors, especially given the final results: higher motivation and engagement of both students and staff, and the academic and social recognition of the quality of their work.

Many of the reforms associated with autonomy in the financial and administrative domains have generated much debate and have been difficult to implement[79]. Some of the academic reforms are also not free from controversy. Nevertheless, freedom to reform curricula and the assessment system are two critical aspects that can significantly improve the quality of education. These are two aspects that can be accepted without much controversy. It is an experiment worth trying.

Academic autonomy means colleges would have the freedom and flexibility to -- design and restructure syllabi; create, implement and adopt innovative teaching strategies; decide on introduction of subjects; decide and alter assessment methods, among others. Academic autonomy will involve the creation of independent boards of studies in each college to design curricula and syllabi.

The shortage of faculty in some departments[80] raises concerns on the capacity of these to setup operational boards of studies. In some colleges, many teachers question their own capacity to design curricula and evaluation system that will meet the highest standards of quality. These concerns can be effectively addressed by the creation of a support platform for the preparation of colleges for autonomy.

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[76] http://www.hindustantimes.com/hteducation/educationnews/ruia-college-granted-status-of-excellence-first-in-india/article1-1188347.aspx

[77] Leena Chandran-Wadia & Aparna Sivakumar, researchers at ORF Mumbai, are currently in the process of releasing a report titled "Excellence through Autonomy: Sharing the experience of College of Engineering Pune: 2004-2014" that discusses the success story of CoEP in detail.

[78] Extracted from document "How a historical engineering college is getting transformed through autonomy" Retrieved from http://iucee.org (Indo-US Collaboration for Engineering Education website).

[79] Admission policy and fee structure, among others.

[80] Some operate with one or two teachers

Creation of small college clusters

One possibility that may lead to good results is the creation of small college clusters: a system of mentorship between one autonomous college institution and two or three colleges in the vicinity. In this model, autonomous colleges and renowned institutions (parent institutions) will mentor the colleges preparing for autonomy. The idea behind it would be to provide faculty training programmes on best practices in education, as well as administrative staff training programmes on best practices in administration. Special grants and other performance incentives should be awarded to the parent institutions and the faculty involved for this purpose, and adequate follow up and assessment mechanisms should be put in place to ensure the up-lifting of these colleges. The parent institutions having successfully contributed to the improvement of two-tier colleges should receive additional performance incentives.

Model of college clusters

1. Selection of a parent institution and three colleges in the vicinity with NAAC accredited 'C' grade or higher ranking.
2. Creation of common boards of studies.
3. Creation of a committee to plan and oversee the transition for autonomy.
4. In the following academic year, autonomy is awarded to the three colleges.
5. For the next two years, the colleges will continue to be part of the cluster, functioning with common boards of studies. At the end of each semester there will be an internal evaluation for course correction.
6. After two years the cluster is ready to be dismantled. Each college will then take up three more colleges, in an identical system as previously described.

According to some of the principals interviewed, not all colleges are prepared, or would be prepared in the near future, to engage in this process of autonomy. Some colleges located in rural areas owe their prestige to their affiliation to a well-established and recognised university e.g. Pune University. In such cases, faculty and non-academic staff fear that autonomy would hurt the prestige of the college[81]. There seems to be a general consensus that rural colleges are not yet prepared to engage in the process of autonomy, mainly because of financial and faculty shortage constraints. Nevertheless, some believe that this could change in the long run[82]. These and all other concerns need to be taken seriously and discussed in a constructive and sensible way.

[81] From an interview with a principal from a college in Ratnagiri district, Maharashtra

[82] From an interview with Dr S.K. Pawar, Principal of SRMM College, Sindhudurga district, Maharashtra.

Recommendations

- Colleges with NAAC accreditation A or higher should take on the mentorship of a cluster of colleges in the vicinity.
- Award academic autonomy to 20 percent of the best science colleges (rated by NAAC as "A" or higher), each year, to design their own curricula, syllabi, and assessment system.
- Implement stringent transparency and accountability standards. Curricula and evaluation policy should be made available in the public domain (e.g. college website).
- Create a support structure for autonomy, by providing consultancy, assistance and sharing of best practices to all institutions in preparation for autonomy. These can be built with faculty from autonomous colleges with proven record of high quality, as well as faculty from other institutions like IITs, IIMs, IISc, among others.
- Organise awareness workshops (for teaching, non-teaching staff, students, parents) on the benefits of autonomy and how to prepare for it (this part should be aimed mainly at teaching and non-teaching staff).

Easing the bottleneck at the postgraduate level

Apart from conferring colleges and universities with academic, administrative and financial autonomy, efforts also need to be urgently directed towards easing the bottleneck that is encountered by students seeking admissions at the postgraduate level. Trends show that even some of the premier universities like Mumbai and Delhi provide limited seats of the respective specialisation at the post-graduate level. This is neither compatible with the ambitious goals of the SAC-PM to exponentially increase the number of researchers, nor with the goal of the Ministry of Human Resource Development to raise the GER in higher education from the present 19 percent to 30 percent by 2020. Seen from a holistic perspective, it is this talent pool of core S&T human resources that will provide India with its future science educators, science communicators and researchers. Therefore, it is imperative that the academically-oriented students are encouraged to pursue higher studies and research, and that adequate opportunities be provided for the same. Universities should be empowered to be responsive and cater to the fluctuating needs of candidates who wish to pursue a postgraduate degree course in their respective field of study and specialisation.

4.2. Improving leadership

The issue of leadership in academia has been widely debated (Brundrett, Burton & Smith, 2003). Leadership is the key factor in the functioning of any organisation: *"Leadership style of college principals affects the ethos of the organisation, which in turn could affect its performance"* (Drodge, 2002 in Muijs et al, 2006).

While in the private sector, leadership has been formally recognised as a key factor to ensure the sustainability of an organisation, very little importance has been given to it in the Indian public sector, where leaders often are chosen strictly on the basis of service seniority. The same problem applies to education at all levels. Revamping of science education requires strong and visionary leadership, not only from principals, but also from teachers (who are leaders in their classrooms). *"Students expect their teachers to be leaders in their classroom; they resent it when it is not the case."*[83] Joseph and Robinson (2014) believe that ensuring planned rotation of roles and responsibilities, coupled with limiting the tenure of the heads of scientific institutions, and putting young dynamic individuals as heads would go a long way.

Hallinger (2003) analyses the differences between instructional and transformational leadership. Instructional leadership, which is a more traditional and top-down approach, is centred on the role of the principal (often senior faculty with recognised expertise and charisma), and on the goals of the institution. The quality of education depends mainly on first order variables like curriculum design and instructional practices. Transformational leadership, a more recent and bottom-up approach, is less centred on the role of the principal, and more on the individual roles of each member of the staff. In this style of leadership the quality of education is controlled by the second order variables like staff capacity building, and their implication on the decision making process (Hallinger, 2003). These second-order variables are directly linked to the first-order ones. For example, teacher training programs will impact their instructional practices.

Hallinger's studies support the use of an integrated leadership style that makes use of both instructional and transformational styles according to the context of each school/college (Hallinger, 2003; Muijs et.al, 2006). Though Hallinger's study of leadership styles is set in the western context, we see no reason to believe that the findings may not apply to the Indian context. It certainly provides for some interesting pointers.

Leadership is a quality that is innate in a very few; however, it can be adequately developed through appropriate training. In a word, leadership is not intuitive, and seniority is not a guarantee of good leadership. Informally, what has been happening in educational institutions is that leadership has been "learnt" based on role models. If the previous leader was a good leader, and the succeeding one was close to him / her, there are good chances that the next leader will perform his / her duties well. On the other hand, leadership can become a disaster without adequate role models for those who do not possess the innate qualities.

[83] Adapted from an interview with Dr. C. Natarajan from HBCSE

The deficiency of academic leadership is largely owing to the fact that most leadership appointments in India have been politically motivated and there are not enough number of academicians who have been groomed to take positions of responsibility in institutions.

Recommendations

- The higher education sector is greatly in need of a separate cadre of professionals to manage the administrative affairs of universities and institutions. We therefore recommend a separate Indian Education Service (IES) on the lines of Indian Administrative Service (IAS) and the Indian Foreign Service (IFS).
- Incorporate periodic leadership training in faculty training programmes. These should be conducted by external experts with proven track record in the field of human resources training.
- Visionary leadership can be fostered by organising faculty workshops on best practices in science education around the world. These should be open to all faculty.
- Strong leadership depends on good relational skills; these can also be improved by adequate training in effective communication.

4.3. Improving the quality of teaching

Revamping teacher recruitment and training programmes

Professional development of teachers is a key area of research in science education (see articles on teacher education in science in Abell & Lederman, 2007).

Teacher training programmes need to be improved, to focus not only on domain specific content -- that is, scientific knowledge associated with each subject -- but also on pedagogy, educational methodologies and technology. Some colleges provide in-house faculty training programmes for their faculty. For example in each semester, Loyola College (Chennai) organises a faculty training program focused on pedagogy and recent advances on educational methodologies. These are compulsory for all faculty members (two full days for senior faculty and one week for junior faculty). These programmes are conducted by external faculty. Other colleges have similar programmes conducted by their own faculty.

> *"Every university and every college should have a department of HR management and faculty training."*
>
> Shri Ashok Kalbag,
> Vigyan Ashram

The Homi Bhabha Centre for Science Education (HBCSE) conducts teacher training programmes in science and mathematics for elementary and high school teachers. In fact, HBCSE also has a website dedicated to just teacher education[84]. The website serves as a platform of discussion, particularly for those teachers who have attended teacher training programmes at HBCSE, to help them keep abreast with the latest resources, and to discuss and deliberate on issues pertaining to teacher education. The website also serves as a repository for teaching resources, useful links and latest news regarding workshops.

Similarly, the Indian Institute of Technology Bombay has reached out to more than 10,000 teachers, particularly those in remote locations, using approximately 300 remote centres where 35-40 teachers gather for receiving live lectures. In the remote centres, the classes are planned with live courses that are transmitted through the internet via a platform called A-VIEW in the morning, augmented with laboratory sessions that are held in the afternoon.[85] These remote centres also function as a gathering point for teachers from different areas to interact and discuss their work and other shared interests. This teacher training model that is currently operating for engineering faculty has immense potential and should be scaled across other fields.

Recommendations

- Create a national working group of experts with well recognised academic track record to design state-of-the-art faculty training programmes in the different disciplines of basic and natural sciences. This programme should be highly focussed on the fundamental core concepts of each field, and revised every two years to incorporate advances in each field.
- Create a national work group of educators to design faculty training programmes in pedagogy, student psychology, educational methodologies and technology.
- Create a science faculty training mission at national level: setting objective and realistic goals and robust implementation and follow-up mechanisms.
- Use the existing platform of refresher courses provided by affiliating colleges but incorporate the curriculum designed by the national platforms described above.
- Create incentives to involve researchers from all centers of excellence in S&T to actively participate in faculty training programmes as facilitators.
- Top science colleges with recognised high quality teaching standards should be encouraged (through financial and other incentives) to extend their own faculty training programmes to other colleges, through formalised partnerships.
- The recruitment process for teachers should not be restricted to just the qualifying exam and personal interview. It should comprise of a three to four stage process which can include group discussions and teaching demos in actual classroom situations.
- Young faculty should be mentored by senior faculty.

84 http://teacher-ed.hbcse.tifr.res.in/
85 Adapted from the Roundtable Highlights and http://www.nmeict.iitb.ac.in/nmeict/empteachers/newrc.php

Improving motivational levels of teachers

Teachers' motivational levels affect their personal well-being, professional performance, and their interaction with the students. Motivation appears to be affected by extrinsic and intrinsic factors (Ryan & Deci, 2000). In the case of teachers' motivation, the extrinsic factors are salaries, incentives, benefits, and job security and the intrinsic factors are sense of self-respect, sense of accomplishment, and sense of personal/professional growth. Many studies on teachers' motivational factors have been conducted in western countries (e.g. Pastor, 1982; Mustafa, 1996; Neves de Jesus and Lens; 2005). Results suggest that teachers tend to be more motivated by intrinsic factors (Pastor, 1982; Mustafa, 1996). According to Pastor, teachers appear to measure their job satisfaction by factors such as participation in decision-making, use of valued skills, freedom and independence, challenge, expression of creativity, and opportunity for learning. Teachers' high internal motivation, work satisfaction, and high-quality performance depend on three "critical psychological states": experienced meaningfulness, responsibility for outcomes, and knowledge of results (Pastor, 1982). Given that motivation may be affected by socio-cultural and socio-economic contexts, these conclusions provide a mere pointer to the Indian context.

According to a UNESCO report (2006), teachers' motivational levels can be enhanced by:

- Enhancing teachers' status in the community;
- Adequate salaries;
- Adequate working conditions (e.g. teaching hours, availability of teaching and learning materials, adequate infrastructure, support of principals and parents);
- Certification of in-service capacity building (e.g. training and mentoring);
- Prospects of promotion and career advancement.

One strategy to raise teacher's motivational levels may be instilling the culture of incentivising or recognising good performance. Today the prospects of career growth in Indian colleges are largely associated with seniority and have little to do with meritocracy. This tendency needs to be reversed. Many other aspects may have a positive effect in motivating teachers: Academic autonomy, faculty training programmes, adequate funding and infrastructure. These are discussed in the corresponding sections.

Recommendations

- Introduce performance based incentives: grants for research, attendance of conference or workshops, sabbatical leave, participation in exchange programmes, to name a few.
- Teacher's outstanding achievements, positively acknowledged by peers, students and management, should be publicised by colleges, in mainstream sources of communication (websites and newspapers); this would have a positive impact in changing society's opinion on teachers and bring recognition.
- Teacher appraisal process should be well-rounded which incorporates feedback from superiors, subordinates, students and peers, often called the 360° appraisal system.
- For better accountability and to prevent exploitation of teachers recruited on contract or clock-hour basis (if and when hired), all faculty duties need to be explicitly defined.
- The compensation of contractual or clock-hour basis teachers also needs to be comparable to the salaries of the permanent faculty of the same grade.

4.4. Use of ICT in science education

The development of new technologies of information and communication is transforming teaching practices and learning environments (Voogt & Knezek Eds., 2008). The Internet has been providing a global platform for the large scale creation and dissemination of information, free of charge and available to all. This has led to a metamorphosis in the dynamics of interaction between teachers and students. We have moved from a unilateral transmission of information (with the teacher as the main holder of information) to a bilateral exchange (where both teacher and students are holders of information).

In this new educational environment teachers and students are naturally forced to change their traditional roles. Teachers have now the opportunity to be the facilitators of knowledge through mentoring, guiding their students on how-to learn rather than what-to learn. Students, on the other hand, have today the unique opportunity to create their own blend of knowledge more easily and be far more actively engaged with their education.

ICT can transform the teaching and learning environment of science education by providing a multimedia platform for: simulations, animations and other virtual experiences; management information systems; data capture, processing and interpretation; and publishing and presentation tools (Osborne & Hennessy, 2003).

Research has shown that ICT use in the classroom can reduce the apathy and distraction levels of students, as well as increase the students' active participation in the classroom and their learning outcomes. ICT can provide support for the development of scientific reasoning and critical analysis and thinking skills (Osborne & Hennessy, 2003).

The development of ICT is a fairly recent phenomenon and many teachers are still unfamiliar with the use of ICT and its advantages in improving learning outcomes. Using ICT in education is not intuitive; it requires adequate hands-on training on the use of hardware and software, as well as on the pedagogic and educational methodologies that involve the use of technology (Osborne & Hennessy, 2003).

ICT can be a leveller. For example, Mexico's use of mobile training units (so called unidades móviles) provides an interesting model for reaching youth at risk of dropping out or those living in rural areas with limited opportunities for learning (OECD, 2012). In fact, the principal of KJ Somaiya College of Science and Commerce, Mumbai, Dr. Vijay Joshi, has been promoting the use of ICT in his college through conventional (smart boards, display systems) and unconventional means (social networking media, cell phone). In this regard, he says, "*Essentially people feel that the use of ICT means initial huge capital expenditure. I don't feel that. There are innovative ways of using ICT… for example, we are using cell phone as a means to do some learning. We developed a database so as to keep throwing questions on students' mobiles. The point is we need to learn their (students) language, instead of making them come to our levels. So if they have a cryptic language, why not use that?*"

> *"So if students have a cryptic language, why not use that?"*
>
> Dr. Vijay Joshi
> Principal, K.J. Somaiya College of Science and Commerce, Mumbai

Over the last two years, Massive Open Online Courses (MOOCs) have attracted a great deal of attention worldwide. Many leading universities have partnered with MOOC providers, like Coursera and EdX, to deliver high-quality online courses, free of charge to millions of students around the globe. Indian students form a large chunk of these learners. "*A geospatial analysis of these users, based on their IP addresses, indicates the vast majority of these users are concentrated in India's urban areas, with 61 percent of users located in one of the five largest cities in India and an additional 16 percent of users in the next five largest cities. Mumbai and Bangalore have the largest concentrations of users, each accounting for 18 percent of Coursera students in India* (Christensen & Alcorn, 2013)."

Nationally, the Indira Gandhi National Open University has been in the forefront of open and distance learning. Today, it serves the educational aspirations of about 1.85 million students in India and about 32 other countries. IGNOU imparts the study programmes through 21 Schools of Study, with a network of 62 regional centres, more than 2050 study centres/ tele-learning centres and around 51 overseas centres. Some of its recent programmes like the IGNOU Sustainable Action and Virtual Education (SAVE) platform offer a wide range of socially and environmentally relevant courses using user friendly technology, at reasonable rates, and has the potential to address a wide range of learners.[86]

86 http://www.ignouonline.ac.in/save/howtoregister.aspx

Recommendations

- Ω Teachers must be provided laptops and unlimited access to free Internet connection along with training in effective use of ICT in teaching and research.
- Ω Classrooms must be equipped with ICT facilities (PC; projector; screen, smart boards, and internet access).
- Ω Creation of digital course content in various subjects, rendered in creative ways, must be accorded high priority.

4.5. Improving the accountability of teachers and educational institutions

As mentioned above the lack of accountability of teachers and educational institutions has been impairing the quality of education.

Recommendations

- Ω Implement a compulsory and systematic mechanism for collecting and analysing students' feedback. Students' feedback must be taken constructively aiming at the improvement of faculty teaching skills.
- Ω Make college and final examination papers available to students for consultation. Provide a detailed correct answer sheet or correction in the classroom.
- Ω Build a pressure group to accelerate the passage of the Bill on National Accreditation Regulatory Authority for Higher Education (pending since 2010).
- Ω Create a national work group with recognised experts in the fields of human resources management and education to design an accountability system to be implemented in all colleges. This should ensure the accountability of academic and non-academic staff.

Note: It has been reported that students who participate in teacher evaluation surveys tend to do it mechanically, where a few students do it for the whole class[87]. There is also the problem of misuse of the survey results for vindictive purposes. One way of addressing this problem is to collect surveys from different batches in order to evaluate by average teachers' performance, and establish mechanisms to protect teachers from misuse of the information.

[87] Private conversation with two students of the Madras University in Tamil Nadu

4.6 Improving curricula

Curriculum reforms in science education have been extensively debated in the literature (Van den Akker, 1998; Atkin & Black, 2006). There is an overall consensus that curricula needs to be made far more relevant to the needs and challenges of society (at national and international levels). The improvement of curricula should focus on two aspects: content and strategy.

Content

Science curricula at undergraduate level tends to be highly theoretical and very dense in content (each subject covers nearly all the core concepts of its area). This poses two problems: 1) Theory is prioritised over application and 2) time constrains do not allow teachers to explore all concepts, in depth. As a consequence, students are frequently exposed to many concepts but fail to understand them in depth and explore their application. This structure results in "teach more and learn less", when ideally it should be the other way around: "teach less and learn more".

Many core concepts in the fields of basic sciences require time and different approaches to be fully understood. When the fundamentals are understood, students can study the rest on their own. Many concepts that are taught in the classroom will never be used by many in their professional lives. It seems therefore that curricula should include only the core concepts and that these should be explored in detail and understood in greater depth. This will allow students to develop a solid grounding in different scientific concepts and provide a background to further develop their knowledge in some of those areas at their own pace, and according to their own needs throughout their professional lives. It is important to keep in mind that concepts evolve, and in interdisciplinary areas new concepts emerge more often, as scientific fields develop in different directions. Therefore, curricula should be designed with a stringent choice of a few but key concepts that will provide the basis for further creation and integration of knowledge.

> *"Science is not taught as a process but as a set of derivations that need to be regurgitated. Because of this, there is total loss of interest for science. Also, in colleges, there is an obsession with covering the syllabus. In engineering, however, there is more connection with the real world."*
>
> Prof. Sahana Murthy,
> CDEEP, IIT Bombay

In India, curricula are designed by Boards of Studies (BOS). These need to include heads of departments, teachers, employers (industry and private sector), alumni, researchers and educators both with expertise on the field in question. This heterogeneous representation is crucial to make curricula more relevant and in-phase with all the pressing needs and challenges faced by individuals and societies in the 21st Century.

Strategy

In spite of a vast body of research in science education leading to the development of new educational methodologies and pedagogy, especially using ICT, our study indicated that very little is applied today in most classrooms.

In science education, there is an old but prevailing dogma that students need to acquire all fundamental knowledge before exploring complex concepts and addressing some of the most prominent scientific problems that puzzle scientists today (this dogma is called the *Pyramid of Knowledge*). In reality very few students get actually exposed to real scientific problems. As a consequence, many lose their interest in pursuing a scientific career and feel frustrated with the amount of theory that needs to be absorbed before getting a glimpse of what the real challenges are. This dogma was recently challenged by Princeton University aiming to revamp their basic science programmes at undergraduate level.

The Princeton strategy includes the following points (Tilghman, 2010):

- Understand what motivates students to become scientists: **Addressing the Big Questions**
- Breaking down the artificial barriers that separate scientific disciplines: **The Integrated Science Curriculum**
- Fostering early research experience: **Laboratorial research projects for undergraduates.**

The next section takes a close look at these issues.

5. THE BIG QUESTIONS

"It is the tension between creativity and skepticism that has produced the stunning and unexpected findings of science."

Carl Sagan

Students are attracted to the sciences by their curiosity to understand the world inside, around and beyond them. Often this curiosity is severely hampered by what Tilghman (November 2010) refers to as the pyramid, the operating metaphor for science education. At the bottom is a group of foundational facts—often discovered hundreds of years ago—that must be learned by heart. Only after one has successfully assimilated those facts is one allowed to move up the pyramid to the next set of slightly more complex facts. Tilghman says, *"these facts are often taught as a laundry list and from an historical perspective, without much effort to explain their relevance to modern problems"*. It will take much perseverance and patience to wait for the *"revelation"* on *"why this is important"* (Tilghman, November 2010).

At Princeton the pyramid is being inverted: Starting with the big ideas, encouraging students to think creatively about these problems and without the support of any educational material or elaborate hypothesis. Only then will students explore what is written in the books and get acquainted to the technical language required to follow these discussions: *"Students are (now) able to understand the concepts and, most importantly, the ways in which scientists go about designing experiments to test big ideas"* (Tilghman, January 2010).

5.1. The integrated science curriculum

The compartmentalisation of scientific disciplines is totally irrelevant for the way 21st Century science is conducted. *"The most exciting problems that scientists and engineers face today often do not neatly fit into one of the foundational sciences but, rather, lie at the interstices of multiple fields. For example, successful environmental remediation will require hydrologists, civil engineers, geoscientists and chemists to work alongside ecologists"*[88] (Tilghman, January 2010).

> *"The most exciting problems that scientists and engineers face today often do not neatly fit into one of the foundational sciences but, rather, lie at the interstices of multiple fields. For example, successful environmental remediation will require hydrologists, civil engineers, geoscientists and chemists to work alongside ecologists."*
>
> Shirley Tilghman,
> Former President of Princeton University

In view of this, Professor D. Botstein has developed an integrated science curriculum for undergraduate students at Princeton[89]. He joined a group of senior faculty in chemistry, physics, and biology and computer science to bring all the important ideas and key scientific principles behind them together. Together they set up a 2-year course. Their students have now entered the best graduate programmes in the US, and the response from the scientific community has been tremendously positive. These students are being trained to work in the interfaces of disciplines.

88 http://www.princeton.edu/president/tilghman/speeches/20100105/

89 http://www.ibiology.org/ibiomagazine/issue-4/david-botstein-an-integrated-science-curriculum-at-princeton.html and https://www.princeton.edu/integratedscience/

Indian Institute of Science Education and Research (IISER) Pune currently has a Centre for Integrative Studies (CIS)[90] that pursues integration of knowledge, with special emphasis on scientific and mathematical inquiries. This centre aims at formulating and addressing overarching questions that liquefy the disciplinary boundaries and facilitate dialogue between and across disciplines.

Laboratory research projects for undergraduates

According to several research studies there is a positive correlation between early research experience and the likelihood of pursuing a scientific career. Students in their senior year of the undergraduate programme in Princeton conduct research projects and are expected to write a thesis based on their results. The early exposure to the research environment will help students to make decisions about their future either as a career scientist or otherwise. This is a very important issue as many students have a glamourised vision of research.

The Princeton strategy provides excellent food for thought and a concept that could be implemented in our colleges. Basic science courses have to include far more interdisciplinary crossing and hands-on learning, through experimentation and scientific research.

In India, CUBE, an acronym for Collaborative Undergraduate Biology Education, is a community initiative by HBCSE, TIFR, with the objective of establishing functional linkages across the educational span, through collaborative research-based program[91]. This may include seminars, workshops, collaborative research, poster campaigns, etc. Students will gain an insight into the research practices, and at the same time be exposed to authentic, interdisciplinary and student-centered learning. Jigyaasa, the undergraduate Science Honours Programme, is one of the most sought after and innovative in-house academic programmes of KC College, Mumbai[92]. This course comprises knowledge enhancement, skill enhancement, field visits as well as a research component. Students are encouraged to pursue a research project, publish their findings, and present their work to their peer groups and external referees from various industries and academic institutions at an event called 'Jigyaasa' (which means curiosity for knowledge).

Recommendations

- Ω Design curriculum with less content but with a stringent selection of key, core concepts from different sciences and knowledge streams.
- Ω Foster interaction of experts on science education with faculty through workshops and partnerships so that colleges can increase their exposure to the advances in education technology, methodology and pedagogy.
- Ω Increase laboratory based hands-on learning experiences and open-ended research projects at undergraduate level. Research institutes can replicate CUBE for encouraging undergraduate research and bridge the gap between scientific community and students.

[90] http://www.iiserpune.ac.in/research/cis
[91] http://cube.metastudio.org
[92] Under the leadership of Principal Dr. Manju Nichani, the SHP was launched during the Golden Jubilee year of KC College (2004-05), to inculcate research culture and personality development amongst undergraduate students.

The role of liberal arts in science education

Our discussion on curricula would not be complete without mentioning the need to create an educational environment conducive to the development of analytical and critical thinking skills, as well as relational, creative and communication skills aimed at making students sensitive to their social environment. In view of this we would like to make a case for the importance of liberal arts for training future scientists and non-scientists as "Humanists".

Chemistry Nobel Laureate, Dr. Thomas R. Cech, has written an essay on how liberal arts education produces better scientists (Cech, 1999). His analysis is focused on USA liberal arts colleges when compared to USA research universities. According to him, liberal arts colleges generate a special environment conducive to creating good scientists, by fostering the development of critical skills like: mastering of specific knowledge domains, oral and written communication skills, analytical and critical thinking skills and the ability to tackle ambiguity and build a well-reasoned opinion. Many of these are due to the cross-training in science, humanities and arts.

Liberal arts colleges provide an environment where students actively interact with teachers (usually the faculty to student ratio in colleges is far lower than in universities). Due to the low faculty to student ratio, students get more individualised attention and classes are more interactive. Students have the opportunity to pursue open-ended research projects in parallel with their laboratorial classes. Open-ended research provides an opportunity to explore real research. The problem is framed and the research procedure evolves through trial and error where the outcome is far less predictable. Laboratorial classes are often based on very well defined problems and research methodologies, aiming to provide a similar experience to many students through a more straight forward approach leading to more predictable outcomes. The open-ended research projects are conducted under direct faculty guidance.

Even if colleges cannot provide research projects in cutting edge areas and access to highly sophisticated instrumentation (due to financial constraints), the close guidance from and interaction with faculty constitutes a most valuable educational experience. Students *"gain skills in identifying and solving problems, reasoning, organising scientific data, presenting their results and interpretations, and along with these gain state-of-the-art technical skills. ...Liberal arts graduates speak of the high level of responsibility and independence engendered by their graduate research experience"* (Cech, 1999). The development of these skills is considered by many very influential in the development of their scientific careers.

"Innate talent and the quality of education both contribute to the success of science students graduating from liberal arts colleges. Intelligence, creativity and hard work can take a student far, but they constitute an even more powerful combination when channeled, guided, and motivated by excellent teachers in an environment supportive for learning". (Cech, 1999).

This can be equally applied to those that will not pursue a scientific career, for the skills that are developed in this kind of environment will be equally useful in other professional contexts. It is said that just as Science, Technology, Engineering and Math (STEM) brought transformative change in the

20th Century, it is expected that Science, Technology, Engineering, Art/Design and Math (STEAM) are set to transform 21st Century! [93]

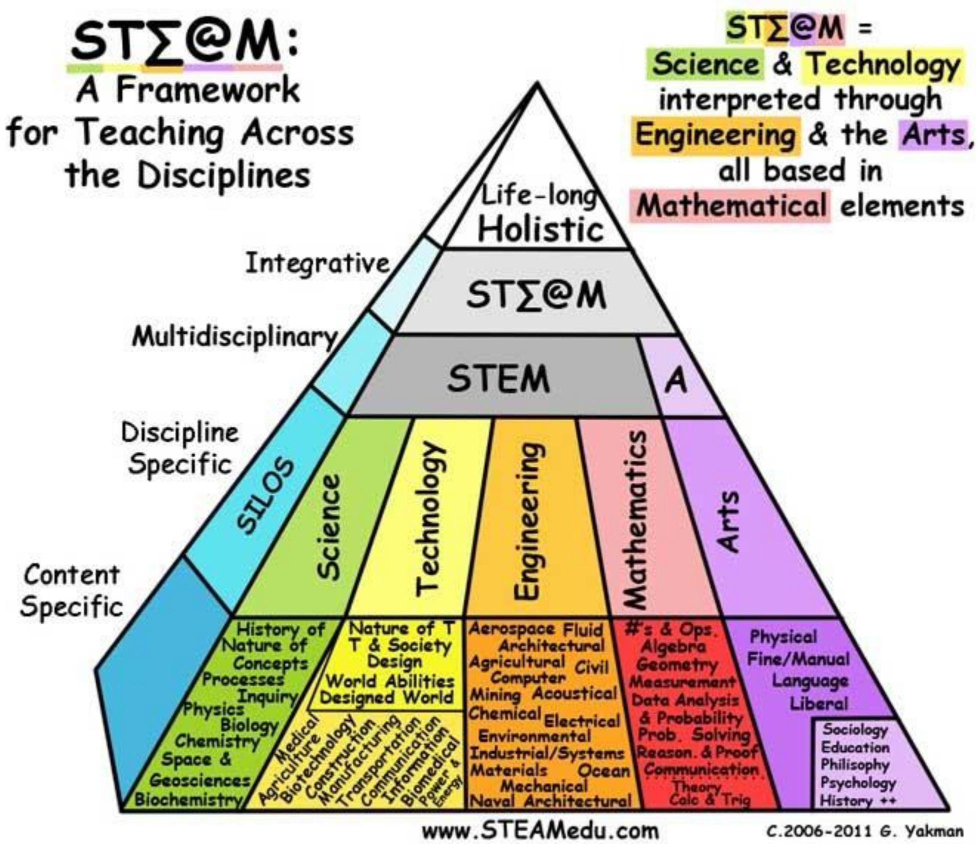

Figure 8: STEAM Education
Picture Courtesy: http://www.steamedu.com/

Recommendations

- Ω Implement choice based credit system across colleges affiliated to a given university so that students can make their choice from a wide range of subject offerings from Science, Arts, Commerce and Fine Arts fields in order benefit from the inter-disciplinary learning.
- Ω Create awareness workshops at the beginning of each academic year on the importance of liberal arts education and on the multiple perspectives that it opens from personal and professional angles.

[93] http://stemtosteam.org/

5.2. Improving the quality of infrastructure

General infrastructure

Research studies in the field of environmental psychology reveal that human behaviour is highly affected by the surrounding environment. Teaching and learning outcomes are therefore affected by the design of infrastructure like classrooms, laboratories, libraries and other common spaces, as well as by their lighting and acoustic conditions.

Most of our classrooms in schools and colleges today were designed based on a 200 year old model: blackboard at one end of the classroom, with teacher's desk in front of it, facing several parallel rows of desks. This model is known to encourage much more of verbal communication coming from the teacher, than from the students (Bower, 1986). In this configuration student-teacher and student-student verbal exchange is discouraged. Experiments have shown that semi-circular and circular configurations are much more effective to promote debate and improve student-teacher and student-student interaction, encouraging students to actively participate in class (Sommer & Olsen, 1980). Debate inside the classroom has been shown to improve learning outcomes among students, fostering critical thinking and problem-solving skills (Springer et al., 1999). Classroom layout is known to affect the social interaction of both students and teachers (Horne, 2004).

Poor classroom acoustics create a negative learning environment, student's attention levels are affected by noises, both external and internal to the classroom, which could lead to difficulty in hearing the teacher's voice. This is particularly critical for students learning in a language that is different from their mother tongue (it is common in Indian colleges where classes are conducted in English, while student's mother tongue is another regional language). Excessive noise levels have a detrimental effect on students' cognitive processing and academic performance (e.g. noise issuing from street activity, roads, trains, planes). Exposures to high levels of noise reduce attention and motivational levels, as well as long term memory and comprehension. Experiments in the UK have shown that the acoustic treatment of classrooms to reduce external noise, improves academic performance (Dockrell & Shield, 2006).

The effect of light on human socio and emotional behaviour is very well documented. Adequate lighting of classrooms has been shown to improve academic performance. The use of natural light, or artificial light simulating natural lighting conditions, as well as the use of colour was shown to have a positive impact on students and teachers, by improving their moods, reducing stress levels and generating a visually stimulating environment (Hunter, 2005).

The aesthetics and proper maintenance of educational spaces generate a sense of well-being and belonging, and have a positive impact on the personal and academic development of both students and teachers.

These considerations may be perceived as of secondary importance when compared with some of the pressing infrastructural problems faced by many colleges. Nevertheless, the aspects mentioned above should be taken seriously into consideration by the education community at the time of future planning, construction, re-adaptation or rehabilitation of spaces for educational purposes.

Laboratories

Laboratories offer a space for hands-on learning through experimentation. The inadequacy of some laboratories and the absence of minimal security standards pose, in some cases, a serious threat to the safety and well-being of both students and teachers.

Laboratories require different security and configuration according to the type of experiments that are being conducted. Nevertheless there are some minimal security standards that should apply to all: good ventilation; large alleys between the experimental benches; non-obstructed alleys and exits; fire-extinguisher; and emergency medical kit. Hazardous consumables should be manipulated in special places with adequate ventilation, and be stocked in a different room, away from light and in a well-ventilated space. Teachers conducting practical classes should be familiar with first-aid assistance.

Recommendations

- Certification of laboratories following minimum security standards.
- Establish penalties for the violation of security standards.
- Provide personal protection material for both students and teachers (gloves, protection glasses) – either free of charge or under payment of fee.
- Provide training on first-aid assistance for all users of lab facilities.

Research Laboratories

To encourage undergraduate research in colleges, teachers and students should be given access to well-equipped research laboratories either in their own college or through a shared platform with other educational institutions.

Research laboratories should not be confused with teaching laboratories. Research laboratory requirements vary according to the type of research being conducted; these often require more sophisticated instrumentation and set-ups, materials and consumables (e.g. laboratories handling biological material require special precautions against contamination; or laboratories where kinetic experiments are conducted require temperature controlled rooms).

Recommendations

- Create/rehabilitate research laboratories in colleges.
- Establish formal partnerships with other educational institutions and private research laboratories to improve teacher's research opportunities and access to state-of-the-art instrumentation.
- Since establishment and maintenance of laboratories and regular replacement of old instruments, is expensive, Indian colleges should develop a system of sharing laboratory resources.

5.3. Widening the sources of funding

The quality of education is deeply related to the funding of educational institutions. As mentioned above, funds are required to upgrade and maintain infrastructure and facilities; attract and retain qualified and competent faculty, as well as non-academic staff; sponsor research activities and participation in workshops and conferences; purchase hard copies or on-line high quality educational material, etc.

Science colleges need to search for new funding sources and diversify their resources. Increasing fee structures is a suggestion that has generated much controversy and opposition on grounds that fees need to be low to ensure equity in access. Nevertheless, the existence of a coaching industry operating millions of coaching centres around India has shown that families are willing to pay high sums, and even get into serious financial stress to ensure that their children excel in the fiercely competitive entrance examinations to professional courses: the passport for a financially secured future (Devi & Singh, 2011). The coaching industry is valued at $5.1 billion for Class XII and undergraduate education. The revenues of this parallel "educational" system would be a substantial contribution with which to revamp education in the formal sector. This clearly shows that the fee structure and policies needs to be revised. The Indian government is far from having the capacity to fully subsidise education and therefore other solutions need to be considered, in addition to increasing the fees substantially for those students who can afford to pay.

A special programme for equity needs to be designed so that those who are really not in a position to finance their education also have a real opportunity to study in high quality educational environments. Today in the name of equity, these students have primarily access to low quality educational environments. Apart from fee structure, educational institutions should be encouraged (and spared of excessive bureaucracy) to set up new un-aided courses with fees that would generate a surplus to be re-invested in other courses. Educational institutions should have the autonomy, under stringent financial accountability, to undertake consultancy assignments and sponsored research, and generate resources internally through organising workshops and conferences, and cultural activities (performing arts festivals, exhibitions, among others).

Recommendations

- Revise the fee regulatory policy. Empower individual colleges to raise the fees for those students who can afford to pay. For others, government should introduce a large enough needs-based financial assistance system.
- Reduce the bureaucratic control on colleges wishing to offer new courses.
- Encourage colleges to carry out fund raising activities in the form of organising workshops, conferences and other cultural activities.
- Make a college's performance in undergraduate research a major criterion for awarding block grants. The college's performance needs to be subject to periodic review.
- Encourage contributions from alumni.

5.4. Improving Institute-Industry and Institute-Agriculture linkages

The participation of the private sector in sponsoring science education exists but is still very low. Apart from some donations usually in the context of alumni participation, objective strategies need be put in place so that the sponsoring of education becomes a part of corporate responsibility and with tax benefits.

One of the reasons behind the scarce investment made by the private sector in educational institutions could be the absence of effective communication. This gap needs to be bridged and both sides need to be sensitised on their interdependence, and on the importance of cooperation. On one hand the private sector needs a skilled workforce to support business plans forward. On the other hand, educational institutions train the workforce. Unless there is an element of complementarity, students will tend to opt for careers that are divergent from their courses of study. The stakes are therefore very clear, for both employers and educators, and this should push them into a much more vibrant interaction.

Many employers spend significant amounts of time and financial resources to train their employees and bring them to operational levels. It is clear that the role of educational institutions is not simply to mould future employees; its role is far wider than that. Nevertheless, educational institutions should also be made accountable to future employers for they have the responsibility to impart a certain number of critical skills that will ensure the employability of their students. The present gap between educational institutions and future employers is highly detrimental for both. Both sides need to fully acknowledge their interrelated roles and engage in a fruitful dialogue leading to cooperative action. This could be accomplished through the creation of independent non-profit platforms that would bring the private sector companies together with science colleges.

Recommendations

- Create platforms such as job fairs / career melas, to bring the private sector closer to educational institutions.
- Increase the participation of the private sector on the Board of Studies of educational institutions.

India's vision of 'Inclusive Development' cannot come true without rapid rejuvenation of the rural economy. It is sobering to remind ourselves that nearly two-third of India's population is still rural. The rural economy cannot be revived without agriculture and allied activities becoming highly remunerative and capable of providing large-scale livelihood opportunities in and around villages. This in turn requires massive infusion of scientific knowledge, both modern and traditional, efficient management practices, and a local work force properly trained in both.

Hence, any vision of improving science education in India must take into account the urgent need to strengthen Institute-Agriculture linkages. This should happen by integrating both school and college education in rural areas with the challenges and opportunities in the socio-economic environment around them.

Recommendations

- Introduce agriculture, agro-businesses and allied activities (including arts and crafts, animal husbandry, dairy, veterinary sciences, etc) as subjects in the curricula of schools and colleges in rural and semi-rural areas.
- Syllabi and related teaching materials in these subjects should be developed in local languages, with a strong focus on practical activities.
- There should be special training, with attractive incentives, for teachers to teach these subjects. Successful farmers, master craftspersons, entrepreneurs, and bankers and government officials dealing with these subjects should be included as visiting faculty.
- There should be a strong emphasis on creating local employment and entrepreneurship opportunities for college graduates. An equally important point of emphasis should be raising the productivity of agriculture and allied activities in the area in which the college is located.
- Especially for these courses, colleges should open their doors to practising farmers, artisans and rural service providers who are interested in acquiring new scientific knowledge. College managements should be both empowered and incentivised for offering short-term and long-term certificate courses, running summer schools, workshops, etc to meet the needs of the rural community.
- Both regular students as well as community members who undergo training in these courses should be publicly honoured. Such public recognition enhances the social prestige of those choosing to study agriculture and other allied activities in the rural economy.
- Krishi Vigyan Kendras (there is one KVK in almost every district in the country), agricultural colleges, veterinary colleges and similar specialised institutes should be incentivised to link up with colleges offering above-mentioned courses.

5.5. Improving employability

Employability is dependent on market flows and societal needs, and on skills and profiles of future employees. While the former are beyond the control of educational institutions, the latter are not. Educational institutions have the responsibility and the capacity to impart the required skills and knowledge that will guarantee the employability of their students. Employability will surely improve when: educational institutions and employers (private and public sector) work together with some common goals; curricula are revised to meet the pressing needs of markets and society in general; and when students will have the opportunity to develop soft skills such as communication skills, cultural sensitivity, time management and team work, etc.

Therefore, employability is actually related to all the other points mentioned in the above sections. If those are addressed, the employability of B.Sc. and M.Sc. students is likely to improve substantially. If such be the case, then a rise in the enrolment of students pursuing basic sciences, with a view to embracing it as a career option can be expected.

The private sector is facing significant talent gaps, especially in 'mobile talent'. Mobile talent refers to the capacity of an employee to be operational in different working environments, cultures and functionalities. This requires the development of many skills like communication skills, fluency in English, adaptability and capacity to learn, capacity to think in a critical and logical way, capacity to take risks and to provide solutions when faced with problems. All of these skills can be imparted by a well-designed framework that includes and gives importance to language skills, informatics, performing arts, cultural sensitivity and value education. Although presented in the context of the private sector, these skills are equally relevant for those that will be employed by the public sector either in academic or non-academic jobs. Scientists for instance frequently work in multicultural and multifunctional environments where the above mentioned skills are a requirement to establish successful collaborations, apply for research funds and disseminate their results, among others.

The transition from the academic environment to the professional environment requires a natural period of adaptation, the private sector functions with rules that are different from the ones in the public sector. In view of improving students' employability and smoothing this transition, employers and educational institutions provide compulsory internships (on-the-job-training) in future working environments. These internships are often regarded as a burden for the employers. Internships should be designed in a mutually beneficial way for all stakeholders (students, employers and educational institutions). This can only emerge from an open dialogue between employers and educational institutions. China has undertaken promising initiatives to combine rigorous academic course work with workplace training[94].

Finally, employability is directly related to career opportunities. Students are often not well counselled on future career opportunities. Some educational institutions, although having placement cells, tend to focus only on a few "hot" courses like I.T. and Chemistry, leaving others like Botany or Zoology completely behind. Many colleges do not provide comprehensive workshops or awareness

[94] OECD brochure 2012 (p.29): http://www.oecd.org/about/publishing/IndiaBrochure2012.pdf

lectures on job opportunities for students and parents. This trend is changing and there are a few colleges who are extremely active in promoting career guidance programmes with lectures by potential employers, among other workshops aiming to prepare students for job interviews. These best practices, common in well reputed colleges, can be replicated in other colleges through adequate partnerships (e.g. the cluster model described in the section on academic autonomy).

Recommendations

- Incorporate in curricular activities the development of soft skills.
- Establish compulsory internship programmes to prepare students for the transition from an educational to a work environment.
- Improve placement cell activities: 1) organise series of career guidance lectures focussed on specific employment sectors and specific disciplines, 2) organise workshops on the development of soft skills (e.g. communication, presentation strategies, interpersonal skills).
- Activities and achievements of the placement cell should be displayed prominently in the college premises and website, for better accountability to the student population.
- To cater to the diverse student population, there needs to be a greater diversity of offerings of degree (undergraduate) courses. The diverse "needs" mentioned here refer to the choices students make after their education, for example pursuing a job, or higher studies, internship or pursuing research etc. Each of these would require different sets of skills and training. Hence the need for flexibility of offerings by universities, such as a regular degree with credits and vocational courses, dual-degree, integrated Bachelors and Masters degree, as suggested by UGC Report of the Working Group for Higher Education in the 12th five-year plan (UGC, 2011).

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List of Abbreviations

ACER	Australian Council for Educational Research
BOS	Boards of Study
BARC	Bhabha Atomic Research Centre
CABE	Central Advisory Board of Education
CAGR	Compound Annual Growth Rate
CBCS	Choice Based Credit System
CCE	Continuous Comprehensive Evaluation
CII	Confederation of Indian Industries
CIS	Centre for Integrative Studies
CPE	Colleges with Potential for Excellence
CSIR	Council of Scientific and Industrial Research
CUBE	Collaborative Undergraduate Biology Education
CURIE	Consolidation of University Research, Innovation and Excellence
DAE	Department of Atomic Energy
DBT	Department of Biotechnology
DOS	Department of Space
DRDO	Defence Research & Development Organisation
DST	Department of Science and Technology
DU	Delhi University
FIST	Fund for Improvement of S&T
FRC	Friends Rural Centre
FTE	Full Time Equivalent
GDP	Gross Domestic Product
GER	Gross Enrolment Ratio
GERD	Gross Expenditures on R&D
GSDP	Gross State Domestic Product
GSLV	Geosynchronous Satellite Launch Vehicle
HBCSE	Homi Bhabha Centre for Science Education
HSTP	Hoshangabad Science Teaching Programme
IAPT	Indian Association of Physics Teachers
IBA	Indian Banks' Association
ICT	Information and Communications Technology
IGNOU	Indira Gandhi National Open University
IISER	Indian Institutes of Science Education and Research
IIM	Indian Institute of Management
IISc	Indian Institute of Science
IIT	Indian Institutes of Technology
IQAC	Internal Quality Assessment Cell
ISC	Indian Science Congress
ISRO	Indian Space Research Organisation
IT	Information Technology
KB	Kishore Bharati
KSSP	Kerala Sastra Sahitya Parishad

LED	Light Emitting Diode
MANS	Maharashtra Andhashraddha Nirmoolan Samiti
MHRD	Ministry of Human Resources Development
MIND	Movement in India for Nuclear Disarmament
MIT	Massachusetts Institute of Technology
MNCs	Multinational companies
MOOC	Massive Open Online Course
NAAC	National Assessment and Accreditation Council
NBA	National Board of Accreditation
NBHM	National Board of Higher Mathematics
NCR	National Capital Region
NET	National Eligibility Test
NIF	National Innovation Foundation
NIPER	National Institutes of Pharmaceutical Education and Research
NISER	National Institute of Science Education and Research
NKC	National Knowledge Commission
NPE	National Policy on Education
NSF	National Science Foundation
OBC	Other Backward Caste
OECD	Organisation for Economic Co-operation and Development
PISA	Programme for International Student Assessment
PPP	Public-Private Partnership
PPST	Patriotic People for Science and Technology
PRIs	Public Research Institutes
PSM	People's Science Movement
PURSE	Promotion of University Research and Scientific Excellence
RBI	Reserve Bank of India
RUSA	Rashtriya Uchchatar Shiksha Abhiyan
SAC-PM	Scientific Advisory Council to the Prime Minister
SAVE	Sustainable Action and Virtual Education
SC	Scheduled Caste
SERB	Science and Engineering Research Board
SET	State Eligibility Test
SMEs	Small and Medium Enterprises
ST	Scheduled Tribe
STEAM	Science, Technology, Engineering, Art/Design and Math
STEM	Science, Technology, Engineering and Math
STIP	Science, Technology and Innovation Policy
TIFR	Tata Institute of Fundamental Research
UGC	University Grants Commission
UNESCO	United Nations Educational, Scientific and Cultural Organisation

LIST OF TABLES

LIST OF FIGURES

ANNEXURE 1: LIST OF INTERVIEWEES

Name of College, Location, State	NAAC Accreditation	Person interviewed	Designation
K.J.Somaiya College, Mumbai, Maharashtra	A	Dr.J.K.Verma	Vice Principal
R.Jhunjhunwala College, Mumbai, Maharashtra	A	Dr.S.T.Ingale	Vice Principal
G.N.Khalsa College, Mumbai, Maharashtra	A	Dr.R.K. Patheja	Principal
Birla College, Kalyan, Thane, Maharashtra	A	Dr. N. Chandra	Principal
Anandibai Pradhan Science College, Nagothane, Raigad, Maharashtra	Accredited by NAAC*	Dr.Anil Patil	Principal
DBJ College, Chiplun, Ratnagiri, Maharashtra	A	Dr.Shyam Joshi	Principal
Sant Rawool Maharaja Mahavidhalaya, Kudal, Sindhudurg, Maharashtra	B (2008)	Dr.S.K.Pawar	Principal
S.H.Kelkar College, Deogad, Sindhudurg, Maharashtra	Accredited by NAAC, 5-star	Dr.B.N Bhosale	Principal
Athalye-Sapre-Pitre College, Devrukh, Ratnagiri, Maharashtra	B+ (2004)	Dr.N.P.Tendolkar	Principal
Ramnarain Ruia College, Mumbai, Maharashtra	A (2007)	Dr. S. Pednekar	Principal
Sophia College, Mumbai, Maharashtra	A (2009)	Dr. R. D'Souza	Vice-Principal Science
St.Xavier's College, Mumbai, Maharashtra	A	Fr. Dr. F. Mascarenhas	Principal
Institute of Science, Fort, Mumbai, Maharashtra	-	Dr. B. G. Kulkarni	Principal
Presidency College, Chennai, Tamil Nadu	Accredited by NAAC*	Dr. V. Srinivas	Principal
Miranda House College, Delhi	-	Dr. Prathiba Jolly	Principal
University of Madras, Chennai, Tamil Nadu	A	Prof. Riyazuddin	School of Chemical Sciences
University of Delhi, Delhi	-	Dr. H.P. Singh	Proctor, DU
Jawaharlal Nehru University (J.N.U), New Mehrauli Road, New Delhi	A	Prof. Rajaraman	School of Physical Sciences

Name of College, Location (With District)	Minority Status-Yes/No	NAAC Accreditation	Person interviewed	Designation
D.G.Ruparel College, Matunga, Mumbai	Non-minority college	Grade A	Dr.Golatkar	Faculty, Department of Botany (& placement in-charge)
K.J.Somaiya College, Vidyavihar, Mumbai	Gujarati *Linguistic Minority*	Grade A	Dr. Ghelsasi	Faculty, Department of Chemistry
G.N.Khalsa College, Matunga, Mumbai	Sikh community Minority	Grade A	Dr.Surekha Gupta	Faculty, Department of Zoology
Birla College, Kalyan, Thane	Non-minority college	Grade A	Dr.Geeta Unnikrishnan	Faculty, Department of Environmental Science
B.N.Bandodkar College, Thane west, Thane	Non-minority college	Grade A	Dr. Vinda Manjramkar	Faculty, Department of Zoology
Anandibai Pradhan Science College, Nagothane, Raigad	Non-minority college	Accredited by NAAC*	-	Faculty
R.Jhunjhunwala College, Ghatkoper, Mumbai	'Hindi-Speaking' linguistic minority status.	Grade A	Mr.Deviprasad Shetty	Placement Officer
Sri Venkateswara College, New Delhi	Non-minority college	-	Dr. Anant Pandey	Head, Department of Physics
Elphinstone College, Fort, Mumbai	Non-minority college	Grade A	Prof. Rant	Faculty
Queen Mary's College, Chennai, Tamil Nadu	-	B+	-	Faculty

Several teachers, and students (doing under-graduation, post-graduation and research degrees) from the following institutes/ universities were also informally interviewed: Ruia College, University of Mumbai, Anandibai Pradhan Science College, SIES College (Sion), St. Xaviers, DBJ Science College, Sant Rawool Maharaja Mahavidyalaya, S.H.Kelkar College of Arts, Commerce and Science, Loyola College. Dr. F.C. Kohli (Indian industrialist and technocrat) was also interviewed. Note that names of several interviewees are withheld in the report, to respect their request of maintaining confidentiality. All interviews were conducted in 2011-2012.

Annexure 2: List of Roundtable Participants: "Whither Science Education in Indian Colleges Today?" – 10 July 2011

- Prof. Shobo Bhattacharya, TIFR
- Dr. Sanjay Deshmukh, Professor, Department of Life Sciences, University of Mumbai
- Ms. Mukesh Dodain, Admin Officer, ICTS – TIFR
- Dr. Roshan D'Souza, Vice-Principal (Sci) Sophia College for Women
- Mr. Vincent D'Souza, Student
- Ms. Roushell Fernandes, Admin Assistant, ICTS – TIFR
- Dr. Radiya Pacha Gupta, St. Xavier's College, Mumbai
- Ms. Himali, Times of India
- Dr. Usha Iyer, Associate Professor, K J Somaiya College of Science & Commerce
- Mr. Ashok Kalbag, Vigyan Ashram
- Ms. Chetana Kamlaskar, Assistant Professor, YCMOU
- Ms. Kalpana Kannan, IIT Bombay
- Dr. Vidyagauri Lele, Acharya & Marathe College
- Dr. Sunanada More, Yashwantrao Chavan Maharashtra Open University
- Prof. Kannan Moudgalya, IIT Bombay
- Prof. Sahana Murthy, CDEEP, IIT Bombay
- Dr. Sameer Murthy, TIFR
- Dr. Renuka Narang, Education Consultant
- Dr. Sujatha Parameswaran, Assistant Professor, VJTI
- Dr. Bina Punjabi, Principal, Guru Nanak College
- Prof. B.J. Rao, TIFR
- Ms. Snehal Rebel, Hindustan Times
- Prof. Pradeep Sarin, Physics Department, IIT Bombay
- Mr. Satwik Srikrishnan, Student, Ecole Mondiale World School
- Mrs. Farhanaaz M.Syeed, College of Home Science NN
- Dr. N.P. Tendolkar, Principal, Athalye College, Devrukh
- Dr. Priya Vaidya, Asst. Prof. Guru Nanak College, GTB Ngr, Mumbai

Dr. Catarina Correia presenting her study to the panel

Prof. Ashok Jhunjhunwala addressing the roundtable participants

Dr. Sanjay Deshmukh addressing the roundtable participants

College teachers participate in discussions during the roundtable

L to R: Dr. Leena Wadia, Shri Sudheendra Kulkarni and Prof. Ashok Jhunjhunwala during release of the book *"2010-2020 India's Decade of innovation – When will we get serious about innovation education?"* authored by Dr. Wadia

L to R: Prof. Kannan Moudgalya, Dr. Sameer Murthy and Mr. Ashok Kalbag look on as Prof. Shobo Bhattacharya addresses the roundtable

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Catarina F. Correia is a science education researcher. With a PhD degree in Physical Chemistry by the University of Lisbon and ten years of fundamental research in chemistry, Catarina moved to science education research. At ORF Mumbai she worked on science education policy at tertiary level. As a researcher at the Freudenthal Institute for Science and Mathematics Education at Utrecht University she worked on pedagogical content knowledge for upper secondary chemistry courses. She is currently in London collaborating on science education projects with the STEG group at King's College London. She can be reached at: catarina.filipe.correia@gmail.com

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About ORF Mumbai

Observer Research Foundation is a multidisciplinary public policy think tank started in Delhi in 1990 by the late Shri R K Mishra, a widely respected public figure, who envisaged it to be a broad-based intellectual platform pulsating with ideas for nation-building. In its journey of over twenty years, ORF has brought together leading Indian policymakers, academics, public figures, social activists and business leaders to discuss many issues of national importance. ORF scholars have made significant contributions towards improving government policies, and have produced a large body of critically acclaimed publications.

Beginning 2010, ORF Mumbai has been re-activated to pursue the foundation's vision in India's financial and business capital. It has started research and advocacy in six broad areas: Education, Public Health, Urban Renewal, Inclusive and Sustainable Development, Youth Development and Promotion of India's Priceless Artistic and Cultural Heritage. It is headed by Shri Sudheendra Kulkarni, a social activist and public intellectual who worked as an aide to former Prime Minister Shri Atal Bihari Vajpayee in the PMO. ORF Mumbai's mission statement is: ***Ideas and Action for a Better India***.

ORF Mumbai's ongoing initiatives:

- ORF Mumbai has launched a bulletin called **SanitatioNow** as part of its commitment to the goal of 'Sanitation for All'. The Mahatma Gandhi Centre for SanitatioNow is soon to be launched, dedicated to research, advocacy and leadership training in sanitation in particular, and in general, to eco-friendly and holistic development of slum communities in urban India.
- ORF Mumbai has facilitated the creation of the **Mumbai Transport Forum**, a broad-based platform of transport experts, academics and advocacy groups working towards improving the public transport systems of Mumbai.
- ORF Mumbai has collaborated with Ratan J. Batliboi Consultants Private Limited (RJBCPL), one of India's top architects and town planners, to initiate projects for the revitalisation of Mumbai's freedom movement heritage. The project is based on the tenets of **'Placemaking'** – a term for creative redevelopment of multi-use public places.

- In the area of public health, ORF Mumbai is working for a sustained **campaign for TB control in Mumbai** through public-private-people partnership that will rigorously debate, advocate and act on the core solutions which can realistically and significantly reduce TB burden in Mumbai over the next decade.
- A key endeavour of ORF Mumbai is in the sphere of **women's safety**, for which, it has forged healthy partnerships with the MCGM's Savitribai Phule Gender Resource Centre and the Mumbai Police.

CHANGE AGENTS FOR SCHOOL EDUCATION AND RESEARCH (CASER)

ORF Mumbai has launched a neutral, broad-based platform called Change Agents for School Education and Research (CASER) for working towards connecting excellence, research and advocacy to strengthen the school education system, making it more holistic and positively affect millions of school children, irrespective of their background or constraints.

CASER is a platform that brings together several passionate educationists, educators and teachers, education researchers, representatives from the Government, civil society organisations, service providers, technologists, students, parents and volunteers to connect excellence and research, provide inputs on policy, implementation, conduct roundtables, expert talks, seminars and workshops to contribute towards strengthening the school education system and making it more child-centric and holistic for the millions of children in the state of Maharashtra.

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CHANGE AGENTS FOR HIGHER EDUCATION AND RESEARCH (CAHER)

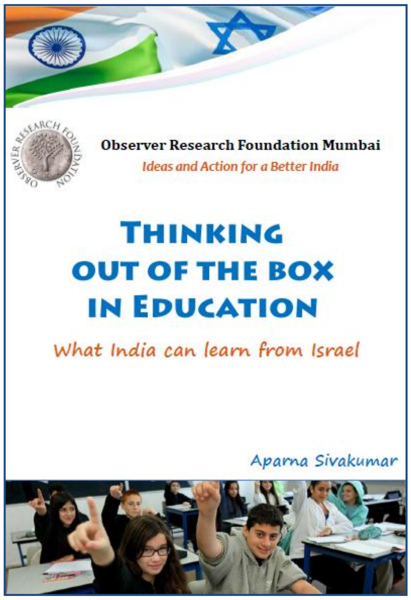
Change Agents for Higher Education and Research is ORF Mumbai's new and novel initiative in the space of higher education in India. As the Government prepares to work towards improvement in the quality of higher education delivery, as part of the new National Higher Education Mission (RUSA), we suggest how this can be achieved in a structured and scalable way through engaging 'Change Agents for Higher Education and Research (CAHER)'.

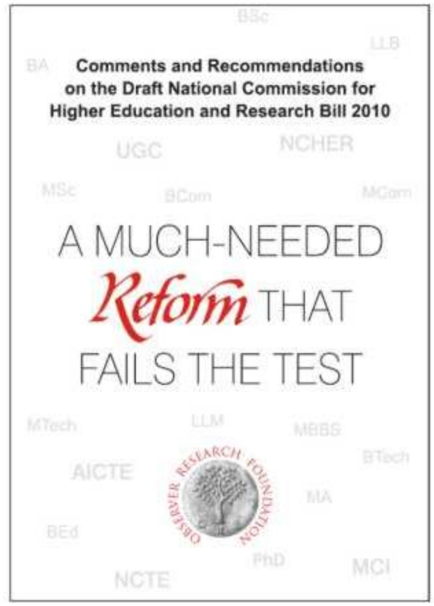
There are two levels at which ORF Mumbai will try to bring about transformation - institutional and individual. We will document and showcase widely the work of individual change agents who are hitherto unsung, such as faculty, principals, and other educators and also the achievements of autonomous institutions such as College of Engineering Pune (CoEP).

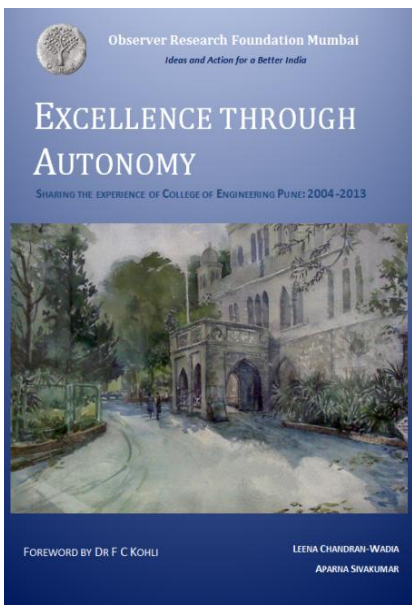
CAHER will be a platform, anchored at ORF Mumbai, which will enable change agents to come together to create a multiplicative effect in the impact of their work. The focus of CAHER will be on quality academics, on capacity building among all stakeholders, and on creating an inclusive and participative movement. CAHER will engage deeply with State governments and with managements and faculty from universities and colleges to stimulate discussion and debate on innovations in higher education delivery. It will also provide innovative ICT infrastructure support for collaboration, to individuals as well as institutions, and advocate for reforms in the governance of higher education.

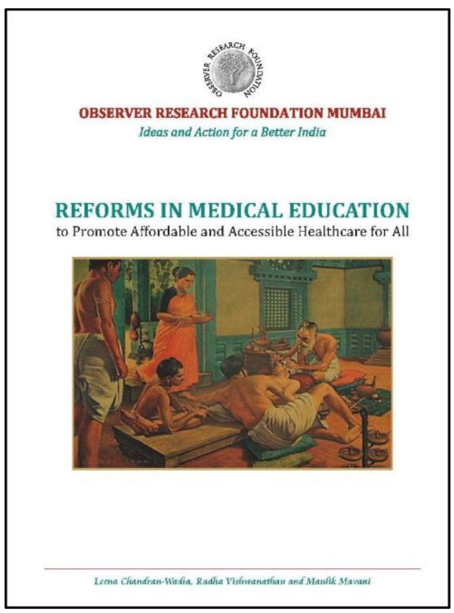
https://www.facebook.com/ORF.CAHER

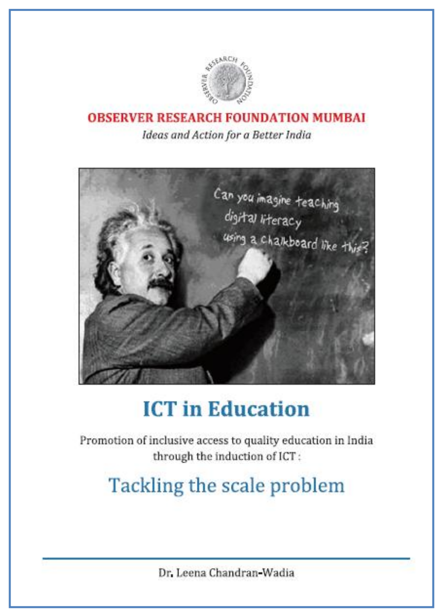
ORF Mumbai's Publications on Education











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