11. In Pursuit of Excellence: Developing a Framework for Post High School Education*

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When the organizers approached me to come here for the inauguration of epiSTEME 4, in one of my weak moments, I accepted the invitation. I have been a teacher through most of my professional life; I enjoy teaching and in fact have nothing to do with science education in real sense of the term! On going over the e-mail containing the information about the meeting, I realized that the epiSTEME Conference, fourth in the series, has coverage of cognitive, pedagogical, historical, philosophical, social, cultural aspects of science education. Apart from the last issue, namely, cultural, I have nothing to do with any of the other aspects. So what I propose to do in this address is to merely strike a note, certainly not provide the 'key' to science education-it is beyond my capability to do that! Then I shall declare the address open for discussion. The Conference programme looks very impressive. So may I first add my personal welcome to delegates from within the country and from overseas, as well as my congratulations to the organizers of this Conference. I see a number of delegates, some familiar, some unfamiliar. I guess by the end of five days of deliberations you will come to know one another, at least you will know each other's areas of interest.

Let me share with you my dream for education! In my 50 years of teaching experience, I still have not found answers to many questions facing educationists. And then I landed with the responsibility along with my colleagues, to set up the *Centre for Excellence in Basic Sciences* within the campus of the University of Mumbai and its genesis is the following. You may be aware that our country has very successfully established the Indian Institutes of Technology and

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Indian Institutes of Management over fifty years ago, largely owing to the vision of Jawaharlal Nehru. These institutes have produced alumni who have been unquestionably successful leaders of national and international corporations. In recent times, the Prime Minister, Dr. Manmohan Singh questioned why do we not have such brand institutions in the area of Basic Sciences? Our country has generously funded programmes in space research, atomic energy, oceanography, biotechnology and clearly they need trained human resource. That's where it struck a chord in my mind and then it resonated clearly when Dr. Chidambaram expressed the possibility of embedding an undergraduate Centre in the post-graduate environment of a University Campus.

India aspires to become a leader in knowledge power in the decades to come and in my view, this can only be realised if our school and post high school education system is strengthened and provided with ample opportunities by way of all-round education. By education, I mean a confluence of science, technology and humanities; I have always regarded a liberal education to encompass all these three aspects. But now how do we go about developing a structure for such an enterprise? This was the challenge we faced when we started planning the Centre. We had hoped to give a well rounded education and in order to achieve this objective, we felt it was highly desirable to consolidate the university system. In post-independence years, the university system in the country was neglected partly because during this period, we have had visionary scientists like Dr. Homi Bhabha and Dr. Vikram Sarabhai who set up Institutes which were mainly research centres and laboratories. Some of us felt that in this process even though these institutes flourished and made valuable contributions to India's atomic energy and space programmes, the university system got neglected to some extent. I don't mean to be critical since I myself did research in such an establishment for a good forty years! Nevertheless, the teaching component was de-emphasized and in my view, teaching and research should invariably go together; they are two sides of the same coin- teaching should ennoble research and research should likewise enrich teaching. Unless we convey the excitement of our research work to students, we are not going to be able to attract them to our research programmes. This is the philosophy which some of us have dreamt of and the question is whether we can implement such a vision in this experiment we have launched.

Indeed, in order to realize our vision for India to become a leading knowledge power, we have to overhaul our educational pattern. I realise the present system has its own shortcomings and drawbacks:

(a) *Compartmentalized teaching and learning of a few sub-disciplines and lack of multi-disciplinary course structures:* Some forty years ago in my undergraduate days in Bombay in this University, the teaching was focussed in narrow disciplines. Modern science has changed its complexion over the years. We must consider biology in relation to physics, mathematics, and chemistry. The tools of mathematics need to be incorporated in biology and chemistry. That's how Francis Crick and James Watson struck gold in molecular biology by incorporating simple topology in their epoch-making work. In some sense one must realise one cannot stand alone in any area; one has to make inroads into neighbouring disciplines and learn from the techniques developed in those fields. And that's what we plan to achieve in our Centre in the hope that we will be able to inculcate among students the culture of interdisciplinarity inherent in modern sciences.

(b) *Inadequate laboratory facilities in schools and colleges:* We still do not provide hands-on experiences to students in schools and colleges. Somehow the training of the mind does not go in unison with the training of hands. This has been a shortcoming of the Indian education system and Indian culture through ages. We have produced great philosophers and meta-physicians. We have their theoretical studies, but when it comes to applications somehow we have lagged behind. Is that the reason why the origins of modern science didn't take root in India? We must address this question. How come the science revolution took place only in Europe and not anywhere in the Islamic world in the Middle East neither in India nor in China? China had a fairly good chance and I have always felt that a few aspects of Chinese civilization were just right for the Chinese society to usher the scientific revolution, but it did not for some reasons. In the eastern culture, somehow the craftsmen were always left out by the upper classes and the intellectual elite did not in any way relate to craftsmen and skilled workers from lower strata of the society. I am sure our Brahmanical pundits were capable of conceiving the technology for developing a wheel, but they did not invent the wheel, probably because they never dirtied their hands!

(c) *Lack of exposure to research methodologies and limited mobility between science and technology:* Major initiatives were not linked academically with the centres of learning and teaching. Thus, the research institutes and laboratories were divorced from the university sector. There were some attempts made, admittedly, by a few enlightened individuals, but they did not get very far. And in a way we did not appreciate enough that the human resource eventually comes from the university or higher education institutions. And that's where we have to make amends in our approach to higher education.

What do we do then to remedy this situation? To begin with we should attempt to translate basic research of today into tomorrow's technology. In fact, this is one major allegation against Indian education system that our theoretical studies have seldom gone beyond the domain of technological application. There were brilliant contributions from Jagadish Chandra Bose, C. V. Raman and S. Ramanujan. Their landmark contributions have found applications more from outside the Indian subcontinent than within! It is essential for us to establish a whole new ecosystem that will nourish innovative solutions and encourage research and development in the university sector and research institutions to be transferred to industries and technological establishments.

I have always felt there should be accountability and academic audit of basic research done in any of the universities, laboratories and research institutions. We ought to switch off programmes which are not fructifying but somehow in our system we are very reluctant to take that harsh decision. I am convinced that it is most desirable to have a regular academic audit if we wish to maintain international standards.

There ought to be, in my view, refresher courses and continuing education courses for teachers and faculty. In fact many of us repeat the same type of lecture-courses year after year. It is also advisable to supplement laboratory instruction by observations of nature and not merely confine ourselves to laboratory demonstrations. There is so much to learn from the flora and fauna and the environment around us. It is useful to recall that observations of planetary motion provided the basis for the development of celestial mechanics by giants like Kepler, Newton and Galileo.

It is necessary for us to promote healthy public-private partnership. We should remember that some of the most brilliant initiatives in our country in the field of education were taken by private endowments like the Tata Trusts. A hundred years ago, Jamshedji Naoroji Tata established the Indian Institute of Science in Bangalore as a Research University. The Tata Institute of Fundamental Research (TIFR) was started by an initial endowment from the Sir Dorabji Tata Trust. We thus need radical changes and massive investments in the country for our higher education, not only from the government but also from private endowments. I remember when I was a post-doc at Caltech, way back in 1966, the year Caltech was celebrating its seventy-fifth anniversary, Caltech had arranged on that occasion a series of Public Lectures, the final one being given by the then Caltech President, Lee Dubridge. The Lecture was titled, "Caltech looks back – and ahead". The first half of the lecture was devoted to recounting all the brilliant achievement by its faculty members like Feynman, Gellman, and Pauling. In the audience there were also sitting the Caltech Trustees: Beckman, Simon Remo, Keck and others. In the second half of the lecture Dubridge said the Institute was getting ample funds from the US government department, like army, navy, airforce to support research activities at Caltech. But we should not solely depend on this source. It will dry up with time, and so let's appeal to the Caltech Trustees for raising an endowment which will sustain the Institute regardless of the government funding. This was a visionary step in the late 1960s. The government funding then gradually declined over subsequent decades. But huge endowments are continuing to nourish the flourishing Centres like, MIT, Caltech, Princeton and Harvard. We must endeavour to get the industrial support which will encourage sustainable development in Science and Technology in the University sector and research establishments.

It is needless to stress that the growth and development of modern Science and Technology is largely dependent on the visionary approach of a few individuals. For example, towards the end of the 19th century and beginning of the 20th century, we had a huge upsurge in education, in social reform and in religion. Thus, Dr. Mahendra Lal Sarkar, a physician from Calcutta started the Indian Association for Cultivation of Science in 1876. That was a very major initiative, because great scientists like C. V. Raman, Jagadish Chandra Bose, S. N. Bose and P. C. Ray were all associated with the institutions in Calcutta including the Cultivation of Science, Presidency College and Science College. And in true sense, Calcutta was the epicentre of such intellectual drives in the country. Jamashedji Tata established the Indian Institute of Science in Bangalore in 1909, Pandit Madan Mohan Malaviya founded Banaras Hindu University in 1916 and Sir M. Vishweshwaraiyya led the foundation of modern technology in India in 1920. Dr. Homi Bhabha and Mr. J. R. D. Tata shared a lofty vision by establishing the cradle of India's Atomic Energy Programme, namely the – TIFR in 1945. Dr. Vikram Sarabhai, in 1947, started the Physical Research Laboratory in Ahmedabad which was the birthplace of India's Space programme. Pandit Jawaharlal Nehru was instrumental in starting the Indian Institutes of Technology (IITs) in 1950, and was, indeed, the patron of some of these initiatives.

I come back again to the question which I raised earlier: why did scientific revolution take place in Europe and not elsewhere in the Arab world, China or India? We can trace the origins of modern science in Europe during the period, 1500 – 1700. At about the same time the Asian civilizations of China, India, and Islamic world were also flourishing, but of course they did not come up with the kind of contributions which the 16th & 17th century Europe did. What was lacking? In the earlier

millennium, from 500 AD to 1500 AD, phenomenal contributions in mathematics, astronomy and physics were made by Indian pioneers such as Aryabhatta, Varahmihir, Brahmagupta and Bhaskara too. They truly laid the foundation of Algebra, Arithmetic and Geometry and Astronomy at the highest level, but their interest was more in pursuing positional astronomy: planetary orbits, eclipses, earth's rotation. We can say with pride that India taught the world how to count by introducing the decimal place-value system and of course proposing the concept of number zero. Likewise, China also had impressive technological development during this time. But then how come they missed the revolution in science that took place in the West! We might recall a metaphor here of the ships waiting in the harbour and when the tide comes, they sail away – a situation very reminiscent of the sudden upsurge in European science. The group of brilliant scientists who formed the Royal Society in the 17th century revolutionized the whole course of natural philosophy. Of course we must recognize that a certain amount of technological knowledge did exist in the ancient civilization of Greece, Rome, India, China and the Arabian world. But save Astronomy most of the developments in science and technology were rather imprecise and qualitative. What was not inherent until the 17th century was the testing of their theories with scientific methodology.

According to A. N. Whitehead, "the essential discovery of modern science was the scientific method itself" (cited in Singh, 1997). Somehow the experimental method is a kind of culture which did not arise here in the East and that was one aspect which has always been lacking in our educational system. Perhaps geniuses like Galileo and Newton come now and then and it's evidently not a continuous procedure. At the same time, there is a view that achievements of geniuses are not through a conscious process, but may be they stumble from time on time on discoveries and they are like sleep-walkers. But if we pause to look back in time, we come across brilliant philosophers of unusual talent from history- men like Plato, St. Thomas Aquinas, Shankaracharya. They were not necessarily contributing to developments in science. But there are other aspects of human affairs which also we must appreciate, such as the contributions of these great thinkers in the domain of philosophy and metaphysics. This also suggests that in the pursuit of intellectual activity there is social and religious ethos which has a role to play at any time. Equally, but for suppression by organised religion, modern science would almost certainly have progressed much faster in Europe. We are painfully aware that Galileo was tortured during his humiliating inquisition, while Bruno was burnt at stake in medieval times. So is theology the culprit responsible for showing down the progress in the middle ages? Admittedly the progress & development of science and technology outside Europe was seemingly hampered by the grip of theology and other similar closed systems of thoughts. This cannot be denied, but it can't be the sole cause.

Let us come back to the counter example of Chinese society. It has been rather free of theological dogma and in fact, Confucianism which was dominant in the Chinese culture was more ethical in character than theological. China should then have initiated the scientific revolution much earlier. It has been suggested that the Protestant Reformation may have been responsible for the scientific revolution in the West. Eventually the value of any intellectual endeavour depends on what view a society takes and how far it encourages and participates in the activity. The reasons for this are probably rooted in technological, economic and social needs of the society. In this context, we should remember the example of Toricelli, who developed hydrostatics -- the physics of fluids. This development was called for by the necessity of regulating mountain streams in Italy in the 16th

and 17th century. The society needed tapping of the mountain streams and regulating the flow of water and Toricelli provided just that. Thus, in some sense requirements of a society also provide the impetus for inventions and discoveries.

It is evident that, science and technology can progress only if we have proper tools and equipments available at any epoch and that is where I think in Europe in the 14th century the emphasis shifted from Aristotelian logic fortunately to mathematics. I believe the key which really triggered the whole revolution in science was provided by the crucial step of introducing mathematics in the calculations and this stimulated great minds like that of Copernicus to conceive a heliocentric view of our solar system and which later enabled Kepler to formulate his laws of planetary motion under the influence of Sun's gravitational field. Newton went on to establish a very formal framework and his inverse square law explained the planetary orbits as well as their precession as they go around the Sun. Clearly, this step paved the way which has, sort of, freed science from its qualitative nature and brought in the important feature of predictability in scientific theories.

One cannot help noting that during the time of renaissance, the university scholars and the intellectual elites generally belonged to the upper strata of the society, along with nobles, merchants and bankers. The prejudice against the association of intellectual classes with manual workers kept the two systems apart. We practically perfected this practice in India with our caste system which was a pity! It is not commonly known that surgeons were clubbed in the same class/caste as barbers and mid-wives, as was, indeed, the case in rural India some seventy-five years ago. In fact, Dr. Wadia, an eminent surgeon, once pointed out that the surgeon's position in some societies was such that they were not supposed to sit with the high-class Brahmins while partaking communal meals - they had to sit apart. Indeed, we distinguished the skilled craftsmen who work with their hands from those who philosophize and promote scholarship. The craftsman and artists were regarded as being inferior to the intellectual and elite classes. It turned out craftsmen who were responsible for the technological discoveries like designing mariner's compass and guns, manufacturing paper and glass furnaces lacked formal education and were not highly valued. Formal education may be a necessary ingredient, but is certainly not sufficient for inventing practical devices. Perhaps this may have happened in Europe in the 16th century unifying the theoretical and experimental components. Of course, we should remember India had produced giants in ancient times like Charaka and Sushruta who developed remarkable modern scientific methodology in the field of medicine and surgery. However, on the social scale they were perhaps treated as being quite lowly. In fact, Dharmasutra has the following admonition: "the food given by a physician, a surgeon, a hunter, an unfaithful wife, a eunuch, a criminal, or an artisan must not be partaken" However, according to Manu who wrote our legal document, "food from a trader who is not an artisan is acceptable". The Indian documentation of Dharmasutra represented the views and prejudices, admittedly of the priestly classes which were probably shared by the society. At large if this was the attitude towards the field of medicine, it was naturally not conducive to the development of this science!

I return to the case of China again. The Chinese Society reportedly did not have such a rigid caste system and the technology in China in the millennium preceding 1500 or so had evidently developed remarkably well. They could have ushered in the scientific revolution, but I still cannot figure out why they did not! The origin of scientific revolution in the West may be traced back to Guttenberg in the 14th century AD. But the Chinese were the originators of printing press technology which I find rather intriguing!

We should also not forget the *Clustering Phenomenon* that seems to operate in science. The Royal Society in the 17th century England is a prime example; its distinguished members Christopher Wren, Issac Newton, Edmund Halley, Robert Boyle, Robert Hooke along with Leibnitz, Descartes, Fermat, Huygens set off an intellectual time bomb. Later in the 20th century, Rutherford's Cavendish Laboratory in Cambridge produced such an intellectual flowering with great scientists like Thomson and Chadwick together with half a dozen Nobel laureate in the Cavendish laboratory. The Cavendish Laboratory of Rutherford flourished in 1930s & 1940s and then came Bragg as the Cavendish Professor who felt that they cannot compete with the Americans and the Europeans in the area of Nuclear Physics which was then the main area of research in the Cavendish. He decided to shift the gear and encouraged two new areas – Molecular Biology and Radio Astronomy, Martin Ryle was given the task of developing radio astronomy, while Max Perutz and John Kendrew were responsible for setting up the molecular biology group. This is something which we ought to introduce in our education system and that is where we need visionary and dynamic leaders who will take that initiative and be bold enough to break away from traditional areas of research. There was, of course, opposition to Bragg during his time. The rest is a glorious lesson in history with the astronomers like Martin Ryle, Fred Hoyle, Bernard Lovell, etc., making their landmark contributions to astronomy and astrophysics during 1950's &1960's, which was the golden age of British astronomy. The succession of discoveries like pulsars, cosmic x-ray and gamma ray sources, and cosmic microwave background sources, all came during that period. That is what a clustering phenomenon basically delivers – the peers feed intellectual fodder to one another and in the process gain buoyancy. And when you see colleagues around you doing great work, you also feel the radiation drag, as it were and get triggered. Of course, the phenomenon of setting off an intellectual bomb cannot go on and on all the time. Thus, in India at the turn of the 20th century, there was a whole blossoming of science culture with J. C. Bose, C. V. Raman, P. C. Ray, S. N. Bose, M. N. Saha, S. Ramanujan making phenomenal original contributions which have significantly influenced the course of science and technology in the world. It may however be added that scale may be an important factor here. In a given environment a cluster may have to be of a size larger than a critical relative size so as to lead to significant and large scale changes such as the scientific revolution.

We should acknowledge that during the course of second half of the 20th Century, we have produced a number of competent scientists in the process building up a plateau in science, though not a striking peak and we must aspire to create such a peak at the same level as contributions of men like Bose and Raman. So the widespread perception that basic science done in India is not relevant for the technology relevant to the country must be dismissed. Historically, Indian science has, indeed, spawned new technology, though ironically not within the country!

Let us again recall some of the original contributions that Indian scientists have made since the closing decades of the nineteenth century. Jagadish Chandra Bose discovered microwaves in 1895 which he used to ignite gunpowder and even ring a bell at some distance without any mechanical or electrical devices. He demonstrated the electro-magnetic radiation at 5-25 mm wavelength for sending communication signals without using any wires through electromagnetic waves over distances of up to a mile in Calcutta. He was the first to adopt semi-conductor junction for detecting radio signals and made pioneering discoveries in plant physiology. He invented radio communication before Marconi, but unfortunately he didn't believe in patenting of his inventions.

A century later Bose's work came handy for the ubiquitous mobile phones and also used in remote sensing, satellite communication, though all this technology emerged in the West, but not in India!

C. V. Raman established the phenomenon of scattered light accompanied by a frequency change, but several decades had to elapse before Raman Scanners came into use in the airports for scanning of molecules, from pathogens to drugs. All these applications were based on the principle of Raman spectroscopy, but again invented elsewhere! Ramanujan, one of the greatest mathematicians of the 20th century whose seminal work on Number Theory in 1930's is finding applications only now in diverse fields like cryptography, computer algorithms, control theory, population dynamics, mobile communication and even theoretical physics. Now, how much of Ramanujan's work have we used in theoretical physics in our country? It is now being introduced in some aspects of string theories and in statistical mechanics. Ramanujan was a creative collaborator of Cambridge Mathematician G. H. Hardy, whose book 'A Mathematician's Apology' (1940/1992, p. 13) should be prescribed for a reading course in mathematics education. It is a book of haunting sadness and frank admission where Hardy writes, "Well, I have done one thing … and that is to have collaborated with both Littlewood and Ramanujan on something like equal terms". That is something which a great teacher can proudly recall at the end of his active professional career that he helped others to contribute even more in the subject and that he has brought them to a stage when he starts learning from his own students.

I come finally to recapitulate the main theme of my address. What is the targeted goal and objective of our Centre? We established the *Centre for Excellence in Basic Sciences* (CBS) to provide a liberal well-rounded education. In this initiative we were encouraged by Dr. Chidambaram and Dr. Kakodkar from the Department of Atomic Energy which gave us a substantial initial grant, while the University of Mumbai provided five acres of land on the Kalina campus to set up the Centre. We were asked what we could do to restructure post-high school science education. There were other Centres conceived about the same time like the Indian Institutes of Science Education and Research (IISER) and National Institute of Science Education and Research (NISER) in Bhubaneswar. But as we noted earlier these were stand-alone Centres, while the Department of Atomic Energy administration showed amazing foresight by suggesting that for our national programmes we should not neglect the University sector which is truly the repository of human resource. It is a pity that some of the influential educationists of our country have given up on the University sector, but there are some of us who still believe that the University sector has a potential which needs to be tapped! We chose to embed the Centre in the University sector on the Kalina Campus of Mumbai University and to let the undergraduate education be part of post-graduate research environment with emphasis on the experimental component within a multi-disciplinary approach to undergraduate education. CBS has a structure where the Governing Council is headed by Chairman of the Atomic Energy Commission and the Vice-Chancellor of the University of Mumbai is the Co-Chairman and then there is an Academic Board composed of distinguished scientists, and the Core Faculty and the supporting staff. The experiment seems to be yielding satisfactory results and let us see how far we can spread this message across the country.

CBS, it should be reiterated, is not a stand- alone centre like either IISER or NISER, rather it is an autonomous entity located in the campus of the University of Mumbai which is academically linked to University Departments and Constituent Colleges. In return, you may ask: What have

we done for the University? Indeed, being part of the university set-up, our classrooms and labs are open and accessible to university and college students. The overwhelming advantage we have had is that the University has given us five acres of land and we have been able to set up the Centre on the Kalina Campus. The Centre is also situated in the proximity of research institutes and laboratories and industries like the TIFR, the BARC and the Homi Bhabha Centre for Science Education (HBCSE). In fact, HBCSE has been associated with us from practically the birth of the Centre, thanks to the efforts of colleagues like Arvind Kumar and H.C. Pradhan, who had made all their facilities available to our students. We did not have our own labs to begin with and we depended heavily on the facilities like the chemistry lab and biology lab of HBCSE with the help of their teachers and instructors. .

At CBS we strive to supplement classroom teaching by laboratory instruction and field trips. We follow a semester system, in which over the very first two semesters, we have classes to cover mathematics, physics, chemistry, life sciences, computer sciences and humanity. We would like to impart an all-round education which encompasses the 'two cultures'. We certainly would not like CBS students to spend inordinate amount of time in front of computer monitors and get drowned by information! We should motivate them how to extract knowledge from the vast pool of information and more importantly how to distil wisdom from this. We do continuous evaluation of their performance, and encourage them to undertake projects in-house as well as in the neighbouring research laboratories. We have access to observational facilities like the Giant Meterwave Radio Telescope near Narayangaon, Pune and the Indian Institute of Geomagnetism in Mumbai. We arrange field trips to such sites and encourage our students to spend vacations at various observatories and laboratories for hands-on experience. And in their fourth year they start doing project work and make presentations of the work carried out by them in the projects. We could not help but feel that the younger generation has really gone much further than what we were at their stage in schools and colleges and this is very gratifying to note!

Students get monthly stipends from the Department of Science & Technology under the Innovation of Science Pursuit for Inspire Research (INSPIRE) scheme, while we provide them accommodation in the hostel on the University campus at nominal charge. We have the advantage of drawing best teachers from proximate labs, research institutions, University departments and colleges to help us with classroom teaching and laboratory instruction. The Centre's teaching and research facilities are made available to students and faculty of Mumbai University. Some of us are in fact, teaching courses in the University departments. Likewise, our laboratories are open to University students too. The entry of students is on the basis of National Level Entrance Screening Test (NEST). This is along the lines of the Joint Entrance Exam of IIT. We decided right from the beginning that we should have our own entrance screening test conducted over thirty nationwide centres in the country, as we are targeting students not necessarily from urban centres, but from non-urban and rural areas, as well. Some of the students who had gained admission to medical colleges and IITs also came and joined us because they were keen on learning basic science and did not necessarily want to do applied science or engineering. This is a very gratifying trend and it seems to have worked effectively in attracting a large number of students desirous of undertaking research in basic sciences. I must record here my gratitude to TIFR, BARC and HBCSE, who have been the backbone of the 5-Year (Integrated) M.Sc. Programme for which the degree will be awarded by the University of Mumbai.

CBS was launched in 2007 with an intake of twenty students, who came from all over India – Varanasi, Patna, Jharkhand, Ranchi, Gurgaon, Chattisgarh, Ratnagiri, Ludhiana, Ballia, Dehradun, Haryana, Indore, Kolkata, Pune, Jabalpur, Calicut, and Mumbai. They came not necessarily from the urban centres but from remote areas and from various strata of the society and from various categories- general and reserved.

In a Centre for Excellence in Basic Sciences like ours, we have multi-disciplinary course-structure in the first year, with students expected to specialize in various streams from the second year. We started with the Physics stream and in subsequent years added Mathematics, Biology and Chemistry streams. The question is often raised: why not establish similar Centres of Excellence in Social Sciences? The idea is that if our Centre's experiment works, then such a model can be replicated on other University campuses in the country, perhaps not everywhere but wherever we have the advantage of proximate research centres, laboratories which can provide the Visiting Faculty and research facilities.

We are convinced the paths of knowledge creation and knowledge application must intersect in order to make rapid strides in sustainable and technological development of the country. And for this purpose we really hope we can train our students to imbibe the spirit of sustainable development in order to address essential issues such as clean environment and climate change, health care for all, water resources and management, food security, energy conservation, solar energy, universal access to education, etc. In the vacations, for example, we should encourage our students to do social service. As they come from all over the country, they can be our ambassadors and can be of help by way of offering community service in their neighbourhood.

In a report submitted to the Union Finance Minister in 1955, the distinguished economist Milton Friedman writes, *"The untapped scientific and technical knowledge available to India for taking is the economic equivalent of the untapped continent that was available to the US 150 years ago"* (Friedman, 1955). He also goes on in the same article to state that he wished he could have supported Prof. B. R. Shenoy, who added a dissenting note to the Planning Commission report on the second Five-year plan, and Nehru who was the then Chairman of the Commission, was generous enough to include it in the plan document. And that dissenting note said that India should not take the route of the Socialistic economic model, rather we should adopt free market pattern, a framework which formed the basis of economic reforms introduced in 1990s.

We need to identify dynamic and visionary leadership for science institutions which could be established as stand-alone Centres like Indian Institute of Science Education and Research (IISER) & National Institute of Science Education and Research (NISER), but selectively also set up such Centres within University campuses. We need to attract the best faculty from all over and provide most congenial facilities by combining teaching of undergraduate classes with world-class research without any bureaucratic interference. We need to formulate a comprehensive curriculum in Basic Sciences in a multi-disciplinary framework with adequate experimental component and maintain a balance of courses in Science, Technology and Humanities. Besides the Core Faculty, we should be able to attract the Adjunct and Visiting Faculty from proximate research centres and laboratories and strengthen academic links with University Departments and constituent Colleges. We need to admit manageable number of talented students from various strata of the society, particularly

targeting the non-urban centres in the country by conducting National Entrance Screening Tests at various places in the country.

We really need to internationalise our science education. A senior mathematician from the US was visiting the Tata Institute of Fundamental Research campus in mid-1990s and I was having tea with him in our West canteen. My visitor looked around and asked me how many overseas visitors do we get and how many overseas permanent staff members are there in the Institute. We only had at that time one mathematician from Spain in the School of Mathematics. The visitor said that he measured the vitality of an institution/centre from the presence of overseas faculty, and visitors spending interactive time at the place. According to him, that was always a measure which serves as a barometer to indicate how attractive the place is for overseas visitors to come and spend meaningful time. I feel that was the right enquiry and we should in our Centre attract young post-docs and even young and senior scientists from the country and abroad to spend time interacting with our students and faculty. We should "globalize" the academic activities of our Centre and to begin with, invite faculties from other institutions in India. One just has to look at institutes like Massachusetts Institute of Technology (MIT), Harvard, Princeton, Yale, Oxford and Cambridge to notice they have a full force of post-docs and young faculty members who really provide the backbone for undertaking cutting-edge research. We ought to follow such a practice and I believe we have the means and resources to implement such a policy.

I should conclude by quoting the testimony of the American Physicist, Robert Wilson when asked to testify before Congress for justifying the huge expense on constructing the Fermilab:

> *"It (the research) only has to do with the respect with which we regard one another, the dignity of men, our love of culture. It has to do with those things. Otherwise, it has to do with: Are we good painters, good sculptors, great poets? I mean all the things that we really venerate and honor in our country and are patriotic about. In that sense, this new knowledge has all to do with honor and country but it has nothing to do directly with defending our country except to help make it worth defending."*
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> (Wilson, 1970a, p. 112-113 cited in Fermi Lab History and Arts Project, n.d)

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DISCUSSION

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Q1: The scientific and industrial revolution in Europe grew out of the European Renaissance which grew out of the Bologna school in 1192. Historically it is an irony that Bologna school's European education system started in 1192 and Nalanda was destroyed in 1193. So Bologna gave rise to Padua that gave rise to Sobor that gave rise to Oxford. That was the beginning of the European travelling and in Asia, this was the end. When Bakhtiyar Khalji destroyed Nalanda, it had decayed so it's not that a vibrant institution was being destroyed by Turkish soldiers. Great things were brought by the Mughals in architecture but there was nothing in terms of university academics and if you again look at China that was their biggest lacuna. There were Confucianism schools no doubt. But university is something that is a repository of knowledge. The investment in universities, a state funding of university, has been a unique feature that distinguishes the European education system from others.

SC: We should now learn from that experience, and must strengthen our university system.

Q2: I agree with much of what you said. To add to your conversation or to broaden your question, we could ask the same question you have posed, not only to India but perhaps to, let's say the so called developing world. And why we have not produced the basis for modern science. Perhaps we should also just extend your interdisciplinary metaphor in the history of science to be read against the political and social history. Then may be one part of your answer to the question also lies in how colonization has worked. So the fact that societies were colonized meant that they could not have the normal development of science that might have happened and I think that would apply to India perhaps as much as it would apply to South Africa, for example.

SC: Partly true, I admit that it is the political part because the invasions and other factors did influence. But ironically in India, the English language was introduced by our colonial masters which stood us in good stead in later developments.

Q3: I thought the effect of colonization was very deep in how it undermined intellectual ideas in those societies. So if we look in the last century, about America in addition to the things you have mentioned, I am saying other factors are also important, like for example- the way the intellectual migration happened. So why is MIT having some of the best intellectuals of India? I think that's very important. So I think a broader analysis is the effect of wars and conflicts in societies. So for example, in South Africa, now that we have a more stable country, we see a migration from much of Africa to South Africa. So, I think that would add to your analysis.

SC: Indeed, stability of the society, of course, does matter, but curiously when we were being ruled by the British during the colonial days, towards the end of the 19th century and the beginning of the 20th century, we had many intellectual flowerings of the kind. I was trying to argue that the landmark contributions of C.V. Raman and Jagdish Chandra Bose and others came during this period. Was it because of the whole social awareness against the political suppression? We don't know, but it did happen. At the same time the British did encourage people like Bhabha and Sarabhai who went to Oxford, Cambridge and other places and benefited from the exposure to the Western education. But by and large, it is true the society does get affected by the rules of colonial masters. The causes have to be rooted in the social and political fibre and importantly in stability of the culture.

Q4: You took Needham's old question. I think there is revisionist thinking on this. There are parallel contributions across Asia. There are also concrete examples in mathematics (e.g Kerala's school of mathematics). The transformation of mathematics in Europe took various interruptions. So there were lot of elements that disaggregate Needham's question, perhaps it's a debate, lot of groups are working on it.

SC: There is a disconnect here and indeed, we should realize that aspect.

COMMENT: I am overwhelmed by the contribution of our distinguished professor and what he has done to open and broaden our minds today. In terms of the issues raised by our distinguished professor he has really touched upon so many different things. He has touched upon history, he has touched upon social, political, economic, religious, moral issues related to education in India. As far as I can see, I can't ask any question but I could comment. There would be a range of opinions on different ends of the spectrum as to what happens in terms of education in India. There were many famous men who had dreams, Martin Luther King - I had a dream, and even Winston Churchill had a dream. And I share the speaker's vision for his dream of science education in India. This is a beautiful start to the conference as we engage the thoughts of each other as to what happens with education in India. As I said I can't ask question, I compliment him on his very distinguished talk.

Q5: I have a question that overwhelms me. Are we giving up on the college system in India? Why are we establishing centres, let's say for science and for social science? Because some of us who come actually and represent liberal education in art and basic sciences, hope that to scale up these institutions would remain of critical importance and have the critical numbers so that the scale up is possible. Otherwise if I look at, say, what Presidency achieved in critical numbers, or let's say, Brown House achieved in social activism, performing arts and politics or St. Stephen's in administration and so on. The question that always comes back to me is why liberal colleges of great excellence and repute don't go critical in the sense of science? A large number of departments instead would be favourable rather than isolated courses in the departments. These centres have to emulate what over almost a century or 60 years, liberal colleges in India have done.

SC: That is a correct observation. You might regard that our centre is a College for Basic Sciences like *St. Stephen's* is in Delhi. That is very true, but how far do you have a cross-disciplinary interaction between departments? Someone pointed out to us 4-5 years ago, why you don't

include law in your course structure? A scientist ought to know about intellectual property or environment law or ethics in science, space law etc. Clearly, you can't cover all aspects of law, but you can at least try and give them a glimpse and that is the best effort you can really make. But what I would like to suggest is now if this model succeeds, perhaps other colleges like *St. Xavier's College* here in Mumbai, *St. Stephen's, Miranda House* in Delhi, *Presidency College*, Kolkata, could learn from our experience, since some of them have already become autonomous. They could follow the same pattern, if they wish to. Of course, we ought to learn from your experiences too. What we should do is really interact very effectively with some of the teachers from these centres which have been demonstrably successful. In fact, in modern world of technological revolution, I do not see why we could not network. Like *Presidency College* in Kolkata can easily network with IISER in Kolkata or in Delhi within the distance education framework.

Q6: What is the role of gender in the development of science education in India, historically?

SC: In our centre we have more women teachers as it happens. But we don't believe in gender inequality at all. We accept a person, a teacher, as he or she is. As it has turned out, our initial hiring was half a dozen lady teachers. So the gender agenda is, in fact, being encouraged, that's my immediate answer. Now, if you want to probe, what needs to be done positively, I would say other things remaining equal, we will certainly like to give an opportunity to women scientists. The cases which are under process, 4 or 5 of them being ladies, their husbands are working as scientists in proximate institutes in Mumbai. They have expertise and inclination to come and teach and we do not have a rigorous system of 9 to 5. So we encourage them to come, teach, and interact with students which is very convenient all round. Regarding the historical aspect, I would say we have a long way to go. When we talk about encouraging women to participate in scientific development, we are conscious of this and we know the contributions of women in the past to development of science and technology in the country. I think in current scenario, certainly they are playing a role as important as men but I am ashamed to admit that in ancient India, the role of women, especially in the field of education was very limited and that's something which the whole caste system and the attitude towards gender was promoting. Unless women were as good as or brighter than men, they just could not break into the system. But unfortunately Manu, our lawmaker pronounced - "*Na stree swatantrya marati marha dei"*. If you don't know Sanskrit, its good- its translation is a little bit embarrassing for our culture.

Q7: I would like to go back to the point by a participant from South Africa, raised earlier. I think it's a very important part of the whole scenario, which is kind of missing in your analysis. In fact, the question you have asked - why scientific development and revolution did not happen in these continents and ancient civilizations? A part of it not only goes back to colonization but is also related with the issue of language. As we know that the History of Science has been written in a certain dominant language that sort of filters down to us and at school level, university level, there is a popular myth about the History of Science and how science has progressed. Obviously, on the way, it has missed various other important histories not only from eastern blocks, Soviet Russia but also China, Egypt and ancient civilization. So I think that needs to be incorporated in your otherwise excellent analysis.

SC: Agreed, I have not touched upon the political aspects. I was going to start with social aspects in relation to education; particularly science education. Maybe if I were to deliver such a talk again, I will bring in both the components-- political and social. But equally, we must not forget that history is written by those who are the victors. History is necessarily a subjective interpretation, and has its prejudices and biases. But what we must not forget is that English in some sense now has come to be the language at the global level. In our languages, we have literature, for example in Marathi (my mother tongue), Gujarati, and Bengali. But now the question is how to produce knowledge in your language. Vernacular language was the medium for us to learn and I was actually taught in vernacular. But basically I think you have to ask this question, we certainly have literature in various languages, but have we produced knowledge? I am making a distinction here between generating literature and creating knowledge. When I was a graduate student, I had to learn French and German because that was a requirement for the Ph.D. degree, but it is not any more. But I am sure Chinese or for that matter Arabic languages have their literature and they have their knowledge too.