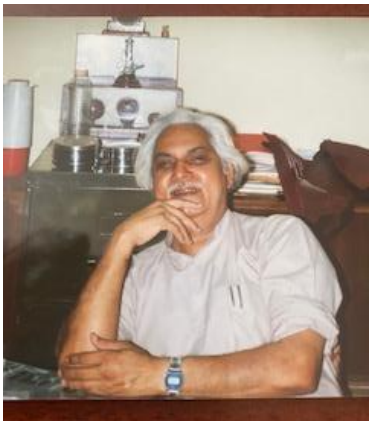
IS DOING GOOD SCIENCE GOOD ENOUGH?



A. How Are Our Elite Institutions Faring?

Many Institutions in India, particularly the well endowed ones like IISc, IITs, IISERs, TIFR, Central Universities, Institutions belonging to DST and DBT etc. are seriously engaged in research and publish their findings in well established professional journals. While comparing the quality of these publications with that of the rest of the international community of scientists, we use citations as an approximate measure of quality. Though not perfect and weak in many aspects, it is a good enough measure for a gross level comparison, in which we are interested.

It is widely mentioned that if a publication gets ten citations, it falls within twenty five percent of the most highly cited papers, while with one hundred citations, it falls within the top two percent. Most of the publications from these and many other Institutions of India do meet the requirement of ten citations. Thus one can safely conclude that the publications from at least these elite and similar other institutions are definitely *Well Above Average* at international level. (Internationally, nearly forty five percent publications have zero citation).

The public by and large is quite appreciative of our scientists but wonders why no Indian has won Nobel Prize after Independence based on the work done in India.

Independent of the country, Nobel Prize winners are peak performers whose quality of research is way ahead of the rest. Generally, if the average standard of research is high the peaks are also likely to be high. When the work is at the highest level of excellence which can influence the work of many, it has a chance of being awarded the Nobel Prize. Indian scientific community too has peaks but they are at present relatively small. There was a major peak in India in the area of Biophysics, whose work was at the highest level of excellence, but he missed this prize. There is no obvious major peak visible at the moment. One hopes that a few tall peaks will emerge soon.

The absence of excellence at the highest level is also discernible from the journals in which the scientists from India are able to publish. In each subject, there is a hierarchy of professional journals, with increasing difficulty in publishing in the best of them. There are also journals belonging to Nature and Science families where it is even harder to publish. Relatively small number of publications from India find a place in the top professional journals, while the numbers in Nature and Science families are so small that most of these institutions may not have a single publication in them in a year. Even the best scientists from India are unlikely to have more than a few publications in these journals (except in Scientific Reports etc.).

This is also evident from the number of Fellows of Royal Society and Fellows of the US National Academy of Sciences. These can be counted on one's fingers. Hardly any work done in India gets commented in News and Views. So is the case with work done in India becoming a part of standard texts.

All the points mentioned above strengthens the conclusion that the research work done in the elite institutions of India is well above average but well below the very best.

B. Implications of Above Average Research

Doing good science and publishing the results in standard journals by itself is quite praiseworthy. However it is not without limitations. There is no discipline in which Indian Science has acquired and maintained leadership position. To some extent it is caused by lack of numbers working in an area, but equally responsible is the lack of required level of excellence demanded in the research work by the existing system.

There is complete absence of Disruptive Technologies originating from India. Most of the Industry continues to depend on imported technologies. These technologies could be easily further modified and made more competitive. The *well above average* Faculty is quite capable of providing incremental improvements in imported technologies existing in the country. But we have yet to generate a successful mechanism which can marry the good quality scientists with industry, resulting in better quality products, improved processes and financially better performing technologies. As a result there continues to be significant dependence on imports while the capability of exports at competitive prices exists, but remains dormant, thanks to lack of close interaction between Faculty and Industry.

Our continued dependence on import of hardware for defence is to a reasonable extent a reflection of our quality of science and engineering capability. For most of our needs we have to depend on Russia and the West and to a small extent on Israel. Our experience in developing even a small civilian aircraft is a reflection of the modest status of innovative thinking in the country. That our efforts to develop Kaveri engine for LCA even after many years of effort has yet to bear fruit fortifies this impression. The quality of publications and the current state of locally developed Technology are not entirely unrelated.

The scholars coming out of these elite institutions are however highly regarded all over the world. Our capabilities are quite visible in Space, Atomic Energy etc. and they are of high caliber which gives all of us a sense of satisfaction. However these technologies, though complex, have been with a number of countries for a number of decades and cannot be reasonably used to claim excellence in science research.

On the whole our elite institutions are producing high quality manpower and above average research, but its peaks are small and have hardly any noticeable impact on high quality science or disruptive technologies. Why are we not producing scientists of very high quality?

C. The Paradox

The students entering these elite institutions represent the intellectual cream of the country. Take for example admission to IITs. Nearly a million students take the JEE Main examination, out of which about one hundred and fifty thousand appear in JEE Advanced for admission to IITs which have around fifteen thousand seats. For every hundred aspirants, less than two manage to enter an IIT. There is intense competition and the test is taken very seriously by students. To enhance their chances of getting admission, most of the aspiring students attend coaching classes which enhance their understanding and their capacity to answer difficult questions which they are likely to encounter in IIT Advanced. Getting admission to an IIT is considered a major achievement and an assured gateway to a very successful future. Admission to other non-IIT institutions in the elite class is equally challenging.

After completing their courses, many students go to the best universities in various countries to study further for their Ph.D. Most of them also gain postdoctoral experience. During their stay

abroad they publish in the best possible journals. It is from this set of super scholars that our elite institutes pick up their faculty as far as possible. With such high intelligence and equally high quality preparation and training, some of the faculty can be expected to produce the highest quality research. What is published from these institutions is definitely quite above average but little in the league of excellent or the very best, which many of them would have already achieved as students or Postdocs. In fact, many not so well endowed institutions like some universities or some of their departments also manage to produce similar quality research and publish in the same or similar journals. One gets the impression that the performance is good but lower than the faculty's full potential. This phenomenon of performing below the innate potential is all pervading and not confined to those who join as faculty members in these institutions or other research establishments. Even NRIs who have had similar training but are. working in other countries under highly encouraging environment are not entirely free from this tendency and take quite some time, if at all, to approach their potential. The ones who produce startlingly new results need to be exceedingly passionate and placed in a highly positive and encouraging environment.

Indians from these institutions are highly endowed with intelligence and have huge intellectual potential but are still not producing the highest quality research. It is an enigma, a paradox. It is necessary to explain why that potential is only partially reflected in our research and development achievements.

D. Why Are We Not Conquering Everests of Research?

There could be a number of reasons, some involving our culture, beliefs and practices, but one of the major ones pertains to our education system, particularly at the primary and pre university levels.

Each child joins school with her/his own latent potential. In a desirable system, the education there should help students unlock and realise their potential by introducing concepts to them,and helping them to assimilate and use them in solving problems. Encouragement in articulation and working with others, providing lots of freedom in thinking and questioning further help the students to realise their potential. Inquisitiveness and curiosity come as additional qualities under such encouraging ambience, where students can use their imagination. A student learns the value of failure while pursuing success. Their fear of failure vanishes. This develops in them an attitude of confidence and belief in their own capabilities on the one hand and love for learning which comes with mastery over concepts on the other. A student blossoms and becomes a scholar and her/his achievements tend to reflect the realisation of her/his full potential.

Unfortunately, our existing education system seems to follow some practices where the full realisation of the latent potential of each student remains severely underachieved. Instead of the desirable system mentioned above, the emphasis is on passing exams and getting degrees required in the job market. There is adequate emphasis on acquiring information (covering the syllabus) but not enough attention towards converting it to knowledge by assimilating underlying concepts and solving problems, not hitherto encountered,using them (A major weakness). Instead, the students are taught to remember formulae and use them to solve problems given in the examination (similar to the ones solved in the class). The students therefore are not comfortable with solving unfamiliar problems by starting from basic principles.

Students are seldom encouraged to find alternative methods of finding solutions for a problem, thereby leaving their latent creative tendencies virtually untouched. Young scholars have enormous interest in using their imagination. Unfortunately that potential strength, so important in later years, for generating new ideas for research, remains unnoticed, uncared,unappreciated, un-nurtured,

unexpressed and unpractised (therefore severely under-developed). For research this capability of creative thinking provides the most important ingredient for excellence in publications and patents.

This neglect has a number of outcomes. Firstly most students find learning experience boring and monotonous. (They would rather avoid school, in spite of the fact that they would miss meeting their friends). Secondly, there is hardly any opportunity for a student to become passionately interested in any subject. Thirdly, an attitude gets developed where the students feel more comfortable in an ambience where new and innovative thinking particularly involving high doses of imagination is not required. Thus they cultivate an attitude of avoiding risk and move as little away as possible from the knowledge they already have. This results in colossal under-preparation of the most vital Human Resource of any country leaving its foundation rather weak and fragile.

Though this weakness gets reduced during higher studies in elite institutions, it seldom vanishes completely. It is long lasting and continues to linger even in their professional carriers to variable extent . Even the Faculty of the elite institutions are prone to carry this attitudinal trait, although to a lesser extent. (This foundational neglect varies from person to person depending on each ones background and training but hardly any person is completely free from it).

In research, it translates into preference for working on familiar issues (extension of Ph.D. or Postdoctoral problems), and picking those problems which can result in decent publications rather than those which are outstanding and worth solving and which can make a difference. Avoidance of failure seems to get higher priority. This preference is not deliberate but arises out of the personality not accustomed to solving very unfamiliar problems.

Exceptions apart, there is a general lack of passion for a topic of research though there is interest in it. As far as possible there is a tendency to operate within the comfort zone. There is limited success in using creativity in solving problems because of its under-development. Even during studies in the elite institutions there is hardly any avenue for creative endeavours, leaving the innate capabilities virtually untouched.

This results in modest peaks in our research landscape. Better research ambience in western countries does help but not fully. It does not completely undo the effects of long time neglect and even those who are doing well would have done much better but for this relative neglect in younger years. Those who have done well and even won Nobel Prizes there have done so while overcoming the effects of this neglect . These cases are rare exceptions, helped mainly by the ambience available to them in the West, their own inborn characteristics of divergent thinking, their great passion and determination, their home support and in rare cases great mentoring by some exceptional teachers.

There is a general recognition of various learning weaknesses particularly about mastering the basic principles and using them to solve unfamiliar problems. That is the reason why most of those aspiring to get admission to the elite institutions undergo additional training by joining coaching classes, which have become quite a huge industry in India. In these classes they improve their understanding and learn how to answer the kind of questions likely to be faced by them while appearing in JEE Main and later in JEE Advanced. The training is mainly focused towards answering questions of the kind likely to be encountered in the JEE examinations. It may be reasonable to assume that almost all students attending coaching classes benefit from them to the extent decided by the quality of the specific coaching establishment and their own interest in learning. Even those who eventually do not make to IITs acquire improved understanding of the subjects they study. In spite of this positive set of inputs, the neglect at school level still leaves an attitude of avoiding risks of potential failures which accompanies students even during their professional carriers.

The attention received during coaching helps in developing analytical skills which partially removes the weakness caused due to inadequate attention in School. However, it does not address the development of imagination and creativity related skills in students leaving this very important trait completely under developed (virtually untouched). As creativity plays a major role in generation of new ideas so necessary in research, its inadequate development can also be contributing towards their not achieving the heights for which they have the potential.

Thus, it is reasonable to assume that our faculty falls short of achieving the highest levels of excellence and conquering Everests of Research because of risk avoidance, poorly developed creativity and lack of passion, all due to inadequate attention, mentoring and encouragement at younger age.

E. The Quality of Publications

Two parameters defining the quality of a publication are its Novelty and Significance.

Novelty: It is not a fixed point on a scale but slides on it, starting with being New, and moving to being Original, Unusual, Revolutionary and Unique. Thus being new is the minimum requirement, and each research publication satisfies it. The more strikingly original it happens to be, the higher it gets rated. Thus an entirely new technique, a new explanation, a new theory, an unexpected new observation all reside at the high end of the Novelty scale.

Significance: This is a measure of the difference the publication is likely to make. It can be divided into subsets as a) Internal significance and b) External significance, which can be further divided into b1. To Industry, b2. To Society and b3. To Policy making.

Internal significance: It pertains to the influence it will have on the scientific community by enhancing the work of various scientists. How wide spread its effect will be and how strongly will it influence the work will decide its value. If it opens up an entirely new area or overcomes an existing limitation, its influence is likely to be proportionately higher.

Industrial Significance: Many developments in Science have resulted in Disruptive Technologies which have made huge difference to our way of life. If a publication has immediate implications towards a new product or a new process, it is highly valued as for as significance is concerned. Such works are also patented so that they do not get used to obtain an unfair financial gain by others. It is not necessary for the publication to contain the whole chain of steps involved in translation. Even one crucial step which is novel and can make a big difference to the technology gets very highly rated.

Societal Significance: The publication can result in social welfare through a novel, low cost technology or practice. Such publications would generally be related to the areas of food, water, energy and health.The basic idea may not be novel, but the work involves novel ways of using existing techniques in obtaining simpler and cheaper processes or products.

Policy Related Significance: Some scientific works can help take policy decisions in areas which are of paramount importance to society. Issues like decisions on GM crops, production and use of stem cells, gene manipulation, safer use of nuclear devices etc. all fall in this category.
Thus those publications which are not only Novel but also make impact on Scientists and others attract greater appreciation.

Most authors have a good idea of the worth of a publication even at its manuscript stage. Grading it on the Novelty-Significance Composite Scale can help in comparing various ideas more objectively.

F. Basic Requirements for Producing Outstanding Publications

Such publications which are expected to reside high on the novelty-significance composite scale are normally the result of following two main steps.

F.1. Ensure Significance

Ask an important question, which is pregnant with scientific potential and can be solved. It need not be such as to be solved in one step. Instead, it may require to be broken up into a number of problems. Even if the attempt to solve fails it should raise other interesting questions of equal importance. As solution can only be as good as the question, formulating the question deserves much more attention than is currently bestowed. The selected problem should score high on the novelty-significance composite scale.

If the problem is such in which nobody is interested, it is unlikely to be important (though exceptions can exist, particularly for questions which are far ahead of the rest and are in the realm of the unexplored).

F.2. Provide A Novel Solution

This is normally achieved through association or analogy with already existing concepts. Intelligence which involves understanding of basic concepts and using them in solving problems in general is quite useful but does not generally result in Novelty for which Creativity is essential. In fact at many places creativity is defined as the ability to produce something which is both Novel and Useful (identical with the requirements for high quality publications).

Though there is commonality and overlap between intelligence and creativity, the two are not identical. While intelligence involves using basic concepts, creativity involves making novel connections between existing concepts. Many investigators have shown that upto an average level of intelligence (IQ 120), there is strong correlation between the two which becomes weak beyond this range. Thus reasonable level of intelligence is required for all levels of creativity though there is no proportionality at very high levels.

Making connections between ideas normally considered far removed from each other requires 'Divergent Thinking' (Also referred to as Associative Thinking).This would imply finding as many potential solutions to a problem as possible and then finding the correct one through analysis (Convergent thinking). Imagination with logic is the key in this activity.

At very high levels of creativity, subconscious mind also plays a part in finding the solution. Some psychologists believe that the solution is obtained in four stages: Preparation, Incubation, Illumination and Verification. Preparation involves concentrating on the problem to the exclusion of anything else. Incubation involves stopping thinking about the problem and letting it incubate in the sub conscience mind. Illumination occurs with the awareness of a new idea. Verification through convergent thinking is necessary to ensure that the idea is reasonable and meets the criterion of scientific rigour. It can be worked on further and applied.

There are other theories of creativity too. There can be a lower level creativity (small c) producing many less novel ideas and higher level creativity (big C) involving less number of highly novel breakthrough ideas. All of us get hunches often. All of them belong to small c category. These are the result of building contacts among neighbouring nodes. Big C is less frequent, but extremely valuable. This involves building contacts among distant nodes.

Thus, the quality of a publication is likely to be higher if it reports very novel findings having strong impact within as well as outside the scientific community. It will normally be the result of high level of creativity displayed by its authors.

Asking an important question (having a defined purpose) and providing a novel solution, both requiring enormous imagination and creativity, provide a real path to reach excellence.

G. Need for Higher Level of Performance

It is quite clear that the level of existing research results in Good Science, but its impact is marginal at best. Our country needs new levels of excellence much above those we are at now, in case we want to contribute non-trivially to Science, Technology, Society and Policy making. The quality of life of our people and the safety of our nation from adventurism of others demands that we raise the quality of Research and use it to achieve leadership position in science, and towards development and improvement of Technologies.

CLEARLY, FOR ELITE INSTITUTIONS OF INDIA, DOING 'GOOD SCIENCE' IS NOT 'GOOD ENOUGH'.

There is a clear need for raising the quality of research publications from the present 'above average' level to a still 'much much higher than average' level, identify peaks and take various initiatives to encourage and nurture them so that they achieve much higher levels than at present.

H. How To Raise The Quality Of Research

There is no standard method available, by which a single action (like spending more resources) can significantly raise the standard of research. Expectation of improved high quality pre-university education can at best be long term, having little relevance to the immediate future. The two processes involved in attaining excellence are : asking important questions and finding novel solutions. Enhancing the quality of these two processes will result in enhancement of the overall quality. This is partially achievable through Inputs from Faculty, Institutional ambience and initiatives, Practices of DST and DBT and the Policy on S and T of the Government. All these play important role in the attainment of the quality of research which eventually appear as publications. We will consider each one in some detail.

H.1. Faculty

The quality of research from an Institution is decided primarily by the quality and commitment of its Faculty. High quality Faculty manages to attract funds, high level collaborations as well as the best available students. The elite institutions put in significant effort in attracting high quality faculty which in turn produces good quality publications. An excellent faculty member should have the following traits:

THE PERSON SHOULD HAVE INBORN TALENT, VERY HIGH INTELLIGENCE, VERY HIGH CREATIVITY, GENUINE INTEREST OR PASSION FOR THE SUBJECT,CONCEPT UNDERSTANDING AND ASSOCIATED SKILLS, STRONG COMMITMENT, HIGH LEVEL OBJECTIVITY, CURIOSITY AND SKEPTICISM, PATIENCE AND PERSISTENCE, BOLDNESS, ARTICULATION SKILL, DESIRE FOR COLLABORATION AND TEAM SPIRIT, TOLERANCE TO FRUSTRATION AND ETHICAL BEHAVIOUR.

This defines a virtually non existent combination present in a single individual. It is virtually impossible to identify a faculty member with all these traits. But each faculty member represents a subset of these qualities, which makes each faculty member different from others (therefore unique). In general, excellence in faculty should translate to excellence in research. At present, there is a tendency in the Faculty towards publishing larger number of articles in good journals rather than lesser number in the very top journals. There is need for revising this by moving towards higher quality from the existing high numbers in good journals. Existing faculty is quite capable of enhancing the quality of their research. A strategy has to be carved and a process to follow that strategy has to be initiated.

a) Unlock 'Still Dormant Potential' of Existing Faculty

Most of the faculty of these institutions have much higher potential than reflected in their publications. This potential can be unlocked and nurtured by introducing a few innovative practices.The goal is less to increase the number of publications and more to enhance their quality. The faculty can achieve this by asking more important questions and finding more novel solutions. For this it is necessary to be more focused, more self demanding, more creative, more communicative and more collaborative. Some of the actions and processes which can be helpful are:

a.1) Ask Right Questions:

Most of the Faculty follow the guiding principle of posing such problems which can result in good publications. Instead of selecting problems for the sake of publications, it may be more advantageous to tackle problems which matter, which may have a purpose, and which can make a difference. Such problems are likely to yield much more impressive publications.

As indicated earlier the quality of a publication is decided by its Novelty and Significance. These can be approximately assessed as soon as the problem is posed without attempting its solution. Each faculty member should prepare a list of important problems in her /his area of research which she /he would like to resolve. Novelty and significance can then be approximately assessed. For example novelty can be valued in five slabs as New, Original, Unusual, Revolutionary and Unique in ascending order of importance. Similarly each class of significance can also be approximately quantified under five slabs of Negligible, Small, Mild, Moderate, and Strong.

The composite of Novelty and Significance can then be employed to identify those problems which are likely to yield very high impact. Only such problems should be listed in the first place, which the faculty member feels confident can be solved.

Unfortunately most faculty members do not pay adequate attention to identification and selection of research problems on the basis of the composite criterion analysis. Instead, a large percentage of them continue their Ph.D. or Postdoctoral topics with minor variations for most of their active careers. Alternatively, they look for gaps in knowledge through literature search.The emphasis seems to be to get publications in good journals, but not necessarily the best ones.

The selection of problems to be tackled is perhaps the most important but relatively neglected aspect of research being currently conducted in India. Not every one can pose an excellent problem. Though years are spent in solving a problem,not even a few weeks are spent in posing it. This is the biggest lacunae in the conduct of research in our country.

The importance of posing problems can be gauged from a statement made by Prof. Jennifer Doudna, Nobel Prize winner in Chemistry for the year 2020 in an interview she gave. She said "I remember when I was in Graduate School, thinking about my advisor Jack Szostak (also a Nobel Prize winner), what made him a great scientist. And the thing that stood out for me was his incredible ability to pick the right problems and go after the right questions" It is interesting to observe that even as a Graduate Student, she appreciated the value of posing the right questions and placed this capability as an important distinguishing feature of a great scientist. Thus, posing the right problems is an extremely important part of doing research. The time spent on it is likely to bring disproportionately high rewards.

Not everyone can pose an excellent problem. Some have called this capability of asking the right questions as having a *Strategic Ey*e whereas others have compared it with having a *Special Nose*. Both these comparisons give an impression that choosing a problem is an entirely intuitive phenomenon. It is quite true that lots of imagination is required to pose a very important problem. Independent of the way the solvable problems get posed (dentified gaps in knowledge, through review papers, discussions and brainstorming, going through the work of high quality scientists, through intuition etc.) the composite '**Novelty – Significance**' analysis gives a reasonably objective procedure to compare various questions and decide which ones are worth pursuing.

It is important for faculty to expend much more effort in posing a problem than at present. It will be advantageous if all faculty members begin with questions being currently pursued by them and perform the novelty-significance analysis on them and try to modify the questions if possible to enhance their value on the composite scale. This can provide a viable starting point.

While listing the problems for eventual selection it is necessary to ensure that the faculty member finds each problem exciting and solvable within the available time frame.
There is a strong likelihood that the problem may undergo some changes while being tackled. This happens often in research. It should not come in the way of posing problems as the modified problem will also be generally equally important. The changes in the problem may also be subjected to the same analysis.

In the initial stages, it may be advantageous to develop some feel for assessing novelty and significance through examining some already published papers of other authors in a few journals. It is best to read an abstract of a paper published around five years back and place it in slots for both novelty and significance. Find the number of citations it has obtained since its publication. Repeat this exercise as many times as required until the faculty member is able to predict the approximate quality of the publication as indicated by the number of citations. The feel thus gained can be extended to the selection of faculty member's own projects.

a.2) Publish In High-end Journals

Faculty members need to identify a list of journals where they would strive to publish at least a part of their work. These should be towards high end in quality where the lowest end publication also is likely to have high value on the novelty-significance composite scale. For example, Nature has a list of eighty two high end journals compiled by experts and easily available at the website

natureindex.com. Nature uses this set of journals while comparing the scientific contributions from institutions, cities etc.The same list can be adopted either as it stands or after some justifiable modifications decided by our own experts. Our highly regarded scientists are quite familiar with most of them and do publish in them. They should increase the frequency of their publications in these journals.

The nature index journals are for work in science. Similar list can be prepared in Engineering if it does not already exist. It may be mentioned that within the journals identified by Nature, the journals belonging to Science and Nature families score much higher in the journal hierarchy and can form a special category of their own. It should be the effort of each faculty member to populate these journals to a greater extent than at present. (Nature Index journals is just a reasonable example. Alternative lists which are even better can be used instead, if so desired).

By answering the right questions, most of the existing faculty can easily publish in the next level journals to the ones they are populating now. This can result in discernible change towards improved quality in the matter of a couple of years.

a.3) Build Creativity Capabilities

Hardly given importance in our education system, creativity plays a major role in research as it helps generate new ideas. It involves divergent or associative thinking, where a problem is examined from as many perspectives as possible. It can make a big difference both during posing the problem (Can the problem be posed differently?) and solving it.

As novel ideas are the result of association or analogy with existing concepts, it is necessary to have familiarity with as many potentially useful concepts as possible. For these, use can be made of mind maps (also called thinking tools) of scientists. A mind map arranges concepts in such a way that central concept (called a Node) is surrounded by derived concepts in the form of a tree. They are excellent tools for organising knowledge. For the research worker, each subtopic of associated areas forms a Node which provides a potential candidate for association or analogy, it is important to have as many nodes available to the faculty member as possible with good understanding of each node.

For enhancing the capacity of producing novel ideas it is necessary for a faculty member to add to nodes available to her /him in a continual manner. Four simple, easy to follow, methods are available for adding Nodes to the mind map. i) A faculty member should avoid teaching the same course for more than five years. She/he should try to teach another course, so that new nodes become available. ii). Learn new topics in associated areas on their own. iii). Write critical review articles in the areas of interest and iv). Audit interesting courses from other departments. These courses should be associated, even though remotely or indirectly, with the research interests of the faculty. Even though auditing, the faculty member should do all assignments and appear in all examinations to gain high degree of understanding of the concepts involved.

Another easy way to add nodes is to pool them by having collaboration with another scientist who brings his own nodes, many of which would be different. Thus the total nodes available to the faculty become more thereby enhancing the probability of generation of new ideas. The collaborating faculty should be able to understand and appreciate each other's ideas for collaboration to be successful. In this case the faculty member does not own but shares the additional nodes.

Having nodes alone is not enough. Effort must be expended to generate as many meaningful connections involving them with the problem as possible. For that IMAGINATION is the key. To nudge creativity, it has been suggested that use should be continuously made of the question **WHAT IF**? Using creativity should be made a habit so that it continues to grow and flourish.

Unfortunately, hardly any mechanism exists to explore and nurture the creative potential of the students through all their education. They develop this capability on their own through other activities, which is normally well below their innate potential. This tends to limit the number as well as quality of new ideas a faculty member has while pursuing a research problem. Constant practice is the only way to remedy this situation.

a.4) Gain Through Collaborations

The Motive for collaborations should be *Improved Quality* and not *More Publications* if a faculty member is not publishing regularly in Nature Index Journals. But collaborators should be identified based on their capacity to add more Nodes to the joint pool. Alternatively they can bring more skills needed for successful attempt towards finding a solution. In general collaborators should bring complementary strengths rather than similar ones. Local collaborations are as valuable as international ones and can be much easier to manage.

The need for collaboration and the nature of collaborators becomes evident if the faculty identifies a very important problem for which he has only partial knowledge. In fact, a faculty member should list such problems preferably after brainstorming with other experts having additional expertise. Problems found through such interactions are likely to be more interesting and more important than those identified by the faculty member alone. The member therefore should participate seriously in discussion and brainstorming groups. In elite institutions and among them, collaboration should be the norm rather than exception as it is now. In the absence of collaborations a faculty member gets deprived of the opportunity of posing and resolving more important problems.

a.5) Discussion With Those Working In Other Areas

The faculty member should have discussions about her/his work with intelligent colleagues not necessarily experts in her/his area of research. These in a way can sometime provide stimulants that activate a node of the mind map resulting in a novel idea. Such stimulants can also result from listening to talks, attending symposia, brainstorming sessions etc. These are invaluable in identifying new problems as well as arriving at novel solutions. By and large Indian research workers tend to be less communicative and each one behaves like an island. This is possibly because of perceived worry of losing ideas. It however extinguishes the possibility of cross fertilisation of ideas to yield improved understanding and entirely novel ideas.

a.6) Change Of Research Areas

After working on a topic for many years, a faculty member does develop a feel for it, but also gets tethered to the familiar approaches, thereby making it difficult to produce and introduce novel ideas. Even if the problems are interesting and important, the approach tends to become routine. They then result in publications of somewhat lower quality and the effort tends to be ritualistic and predictable rather than creative and imaginative. Should that be the case, it may prove rewarding to pursue a new area of research particularly if the member has difficulty with coming up with non-trivial ideas in the current field. Such possibility may be considered every eight to ten years.

a.7) Interaction With Industry

It has been reported that the quality of research of a scientist engaged in basic research in biology improves if he/she spends a part of his/her time (say about twenty five percent) on problems of Industry. This may be applicable to some other disciplines too. This offers a good opportunity to a faculty member not only to pose problems with higher potential significance, but also to add more nodes to his mind map. For application oriented subjects, the faculty can both contribute and gain a lot by having strong interaction with Industry. They can thus add directly to make the industry more competitive internationally, thereby participating in the economic development of the Nation. They would also gain experience in solving problems which cannot be changed midway, a restriction not imposed while working for a degree. This adds to their experience in solving real problems having immediate financial implications. Thus their basic research improves too resulting in dual benefit.

Unfortunately the links of faculty with industry vary between weak and non-existent and there is not enough effort to strengthen them from either side. The numerous initiatives taken upto this time by the Govt. have not resulted in any noticeable gains and need to be revisited. Efforts are required from the highest levels of the Govt to persuade the reluctant players to team up and produce results.

a.8) Invited Lectures

It is rewarding to deliver lectures to professional colleagues in the same or associated areas. The comments and questions there can not only give an indication about the quality of the questions the faculty member is addressing at present but can also give ideas about the further questions that need to be addressed. Similar comments are also relevant for attending Conferences, Symposia etc. In each area there are very important conferences abroad. The faculty member should make it a point to attend at least two of them per year. Any activity which gives rise to new ideas should be definitely pursued.

a.9) Intensify Reading Habit

Many get so busy with activities associated with administration and management that they do not find enough time to read literature. It will be rewarding if each one reads at least two papers per week if not more. Though too detailed a literature search may limit ones imagination, thereby limiting creativity, its neglect can miss major ideas already proposed by others. One should be conversant with main ideas and explore the possibility of providing alternative frameworks. Publications in allied areas not currently pursued by the member should be studied as they provide new nodes for generating novel ideas.

a.10) Searching For Alternatives

As far as possible, one should look for alternative solutions or explanations to the ones given in literature for questions which the faculty member is interested in. The alternative idea may be wrong but it originates with the faculty member and adds to the creative armour of the person. There is likelihood of novelty if one tries to think differently.

H.2. Actions By The Institution

A proactive involvement by the management of the Institution is important to ensure improved quality of its publications. For this purpose, the Institution needs not only to raise the infrastructure

to contemporary international standards but also to introduce or modify many current practices, some of which are mentioned below.

b.1) Take Faculty Selection To A Higher Level

The traits of an ideal faculty member have been mentioned earlier. In practice it is unlikely to come across an applicant who has all those qualities. The most important traits required for producing cutting edge research are high intelligence, high creativity, passion for the subject, strong commitment, high level technical and communication skills, curiosity, patience, self belief and ethical behaviour. Another extremely important skill required is the capability of posing important research problems having high novelty-significance composite index. This is an extremely important facet of a Faculty member which at present hardly receives any attention. A compromised choice of faculty can result in a long term damage to the quality of the Institute and its academic ambience. Equally important are the candidate's antecedents including place of study and supervisor for Ph.D., Postdoctoral experience, quality of publications,and any relevant special quality mentioned by the referees. There is strong need to modify the existing selection process where offers are made based mainly on technical skills and the candidate's antecedents. Other requirements like creativity, commitment, curiosity, self belief, team spirit,ethics etc are not seriously looked at. It is best to involve HRD experts to ensure that the candidate has these very important skills and attitudes. These experts can meet the candidate separately if required. Of particular interest is to know if the candidate can sustain intense interest for the whole career without slackening midway and if he can work with others.

Those candidates who have quality as their first goal while publishing, and have capability of pursuing it, should receive special consideration.

Recruitment of faculty is the most important function of an Institution. An analysis of those places which are producing indifferent quality research (or none at all) will show that enough attention was not paid at the time of faculty recruitment. A time has come when an Institution should be continuously looking for gifted individuals, who are likely to end up as peaks,and putting in effort to proactively attract them as Faculty (failing which, as visiting faculty or collaborative faculty).

It is tempting to suggest picking up best faculty available internationally, but it is not practical as yet because of emolument differential, institute ambience, facilities for families etc. If however a high quality international faculty is available defying all these constraints, the institution should definitely consider recruitment of such a person.

b.2) Make Quality The Prime Requirement

The Faculty of the Elite Institutions has enormous unrealised potential . To unlock it the faculty needs to be challenged as well as assisted (The best performance generally is realised while working under mild stress, normally self generated) . All Faculty should be given a modified version of the Nature index or an alternative set of Journals, in which it should be encouraged to publish. The modifications in Nature Index journals can be made by the local experts without reducing the overall quality. Another set of journals in Engineering should be prepared with the help of experts and made available to those working in the relevant disciplines. The preference of the management for high quality journals should be clear to all. Publishing in these should be specially encouraged. There should be special awards (certificates, trophies, special research grants but no personal money, etc.) given every year to those who publish maximum number of papers in these journals for each discipline. Within this set, special appreciation should be shown to those who publish in Nature and Science family journals. Special grants etc can also be provided for such high performers, who should

be encouraged in all ways available to make them perform consistently at such levels, and attain leadership positions.

While selecting new faculty, this criterion of quality should be one of the prime considerations. This should also be one of the criteria while assessing faculty for promotions. While converting contract appointment to permanent one, the quality of publications should be a major criterion and not just the number of publications and no compromise should be made in this regard.

b.3) Visiting Faculty

Not to talk of permanent foreign faculty, most Institutions have hardly any high quality visiting faculty which spends a semester or more there. Yet, Visiting Faculty of high quality can make a huge difference in the quality of research. Naturally, it will not bring significant benefits if the visiting faculty has not been publishing a majority of her/his papers in the special list of high quality journals. Huge efforts should be made to identify and attract such faculty. They will need special treatment and amenities like housing etc. which should be provided without any fuss.

At the highest level of an institution there should be a strategy to attract high quality visiting faculty as well as action plan to operationalise it. This may actively involve faculty of various departments. The institution should use programmes like VAJRA of DST to support such visiting faculty.

b.4) Subject Rankings

Our Government is keen that our Institutions should improve their rankings and strive to come in the top hundred. To achieve this, each institution is following its own strategy without any visible improvements as yet. A more important feature for the institution should be the Subject Based Rankings. These rankings provide a differentiated information about various disciplines and can pinpoint those departments which are bringing down the overall ranking. It is found that some of the disciplines fall in the top hundred whereas some others in the same institution are in the range 300 to 400 or even worse. Special attention should be paid to these departments both with respect to their faculty recruitment and their ongoing research. It is quite clear that such Departments need advice and review more frequently. Each institution should discuss this low status in depth and clearly identify the reasons giving rise to a workable strategy which should be operationalised with frequent reviews. Special attention should be paid to the kind of problems being addressed and the commitment of the faculty.

b.5) Formal Interaction with Industry

A great tragedy of Indian Science is its failure to make any difference to Industry inspite of availability of such good scientists, though not exposed to Industry. At present the whole initiative of building industrial contacts is left to the individual faculty, even when most institutions have formal arrangements for managing industrial interactions. There is not enough effort on the part of the Institution to build bridges with Industry and have long lasting association with it. A lot can be gained both by Industry and the Institution by associating with each other and making the industry more competitive. The country would like the scientific community to make our existing industry internationally more competitive and also develop entirely new technologies. For this to happen the interaction can not be left alone to grow organically without any nurturing. Instead institutions have to take huge initiatives and put in enormous amount of effort. If necessary, the initial interaction can be supported entirely by the Institution. For a number of Departments whose work can have industrial relevance, interaction with Industry should be as important as teaching. To emphasise the role of industrial interaction between faculty and industry, etc Institute should have a Dean (or

equivalent) of Translational Management whose group should build contacts, persuade faculty and make institution-industry interaction more formal and long standing. Faculty should be encouraged , even persuaded, to spend time in industrial (operational and R and D) setting. This activity should be different from that pursued for encouraging startups, which is equally important.

There is a general attitude of considering applied research to be of lower quality, which is entirely erroneous. During assessments for promotions and awards, equal weightage should be given to such work as to basic research.

b.6) Five Yearly Assessment Of Faculty

Elite Indian institutions provide complete freedom to their faculty so that each can pursue research of his/her liking. However it should not be misconstrued as freedom to choose between working and not working. Some faculty unfortunately tend to lose initiative and move to the level of hardly working or partially working. This mid-career slack can have very deleterious effect on the overall performance of an institution. In fact there is a general impression that only around forty percent or lesser of faculty are producing results in these elite institutions. While not taking away the freedom, an institution has the responsibility to ensure that each faculty member puts in enough effort and remains an asset. For that purpose a five yearly review, conducted seriously, of identified members of the faculty to look at their achievements and plan for the immediate future can be of immense value. If need be, the faculty can have interaction with experts who can be of help both as friendly critics and as advisors to suggest any mid term correction. It can also help in deciding whether a change in area of research can be in the interest of the faculty member. The institution needs to generate mechanisms which ensure that each faculty member puts in maximum effort throughout the person's career and remains a peak performer.

b.7) The Golden Projects

In each institution, efforts should be made to identify those ongoing research projects, out of the ones being handled by the faculty, which have high potential based on novelty-significance analysis. A few (say about ten) of these can be identified as Golden Projects and given special attention and consideration through a specially formed Committee.This committee should meet often and keep the council or governing body (as the case may be) informed about the status of these projects and take necessary action to make sure that there is enough support and advice to make sure of their success.

b.8) Sabbaticals

The institution should encourage its faculty to take sabbaticals at highly regarded places, as a part of Career Enhancement Programme. Similarly, it should try to attract as good faculty as possible from highly regarded universities abroad. Partial sabbaticals for them for a few months should be equally encouraged. Arrangements should exist for those who come on sabbatical to interact with at least a few people during their stay apart from requesting them to deliver special lectures.

Their stay can be utilised for brainstorming on important problems in the concerned areas. This may possibly mature into successful collaborations, at least in a few cases.
Serious consideration should be bestowed on the faculty availing sabbaticals in Industry's R and D for a full or part of a year.

The institution should have a Dean of Career Enhancement whose office should shoulder substantial part of the responsibility of arranging such placements instead of leaving every thing to the faculty member as an individual's enterprise.

b.9) Projections Into The Future

Each Department should try to predict the possible trajectory of growth of its subject over a fifteen year horizon and what role other Departments can play in it. There should be formal intra and inter Departmental discussions on this as often as possible with one of the aims to find new areas where the institution can contribute to their evolution. The Departments can plan their future based on these deliberations. As far as possible, there should be efforts to identify novel interdisciplinary problems which do not fall in the category of filling the gaps. When identified, collaborative efforts can be mounted to initiate research activities in them. Even if new areas do not get identified in a near time horizon, the discussions will raise and address many issues pertaining to academic development like identification of important problems, needs for collaboration etc.

b.10) Brainstorming Groups

The Institutions should have many brainstorming groups which meet reasonably frequently. Their main purpose should be to identify important problems in their areas and identify which of them can be handled by individuals and which require collaborations. They should be interdepartmental in composition. Predicting the development of various topics should be one of their important tasks.

The main purpose of these Groups is to *UNLEASH IMAGINATION*. Though ideas occur to individuals, they are helped by ideas thrown up during discussions which act as triggering agents. In the absence of any formal discussion platforms, faculty members act as small individual islands having no connection with others thereby denying themselves both of additional nodes as well as triggering agents. Brainstorming groups will meet both these requirements.

b.11) Best Project Awards

Every year a few awards should be given to those projects which have proven to be high on novelty-significance scale and have published their results in high end journals. The awards should be given to supervisor-student teams.

b.12) Make Collaboration The Norm

Our Scientists generally work alone whereas many more opportunities exist in areas requiring expertise of more than one. The faculty needs to be sensitised to these opportunities and encouraged to participate in brainstorming sessions leading to collaborations. The management should try to involve at least twenty five percent of its faculty in collaborative projects.

b.13) Generate a Happening-Place Ambience

An enormous boost to high quality research occurs when scholars of the institution discuss it and appreciate it. The Management can introduce such practices that help generate a buzz in the place. Firstly any publication of high significance should be summarised in non-expert language and emailed to all students and faculty. Simultaneously, a link to the original can be provided for those who wish to study it further.

Secondly, the faculty who have published important results may be requested to make short presentations (say half an hour) understandable to non-experts. At any meeting, two such presentations may be organised (once in a few months).

Thirdly, there should be special write-ups and discussions on important problems being addressed at the institution, their implications and the possible national and international impact they can make if solved. An example would be a short write up on each of the golden projects highlighting their implications and importance.

Fourthly, there should be an annual competition where students pose their own problems and suggest approaches to solve them. The best problem cum presentation may be given a good award (say Rs 50,000/- at least) and a certificate. All these activities will kindle enough interest among student community and faculty that they discuss these with one another, generating a buzz of enthusiasm and interest in research in the institution.

When good ideas start getting discussed and appreciated, the value of posing problem with a purpose gets established leading to an attempt to pose even more important and worth while problems. Also, a new desirable value system gets established with a huge positive potential. It is extremely important that each student should feel a part of the Institute, and eager to contribute in various ways.

H.3. Role of Fund Giving Agencies Like DST, DBT Etc.

Lots of credit for good quality science being conducted at present goes to these organisations.Most of the faculty members depend on one or more of these agencies to obtain support for their research. Through a number of positive initiatives, they have succeeded in increasing the scientific output in terms of number of publications in good journals to a significant extent. Though the output has increased, its quality has improved only marginally. The added numbers of existing quality papers, welcome though they are, hardly make any difference to the addition of new concepts or development of new technologies. The quality has to significantly improve if science research conducted in the country has to add to quality of life of her citizens or bringing recognition to the country for her high quality Science. These organisations have to shift their emphasis in favour of quality and take additional initiatives to demand as well as reward quality. The existing ambience in Science management in India hardly has any feature to ensure sustained improvement in quality, while it has many programmes to increase volume of research of the existing overall reasonably good quality.

An important characteristic of Indian Science is that its scientists face primarily internal competition. A research worker publishes in foreign journals to show better performance than that of the local competitors and not international ones. Such a system has no ingredient to ensure continuous improvement in quality. All the recognitions including Fellowships of the Academies as well as Bhatnagar Prize and other awards are bestowed without any requirement that the candidates should have crossed some minimum predefined standard of quality. All that is required is to be better than their competitors. One solution is to define a quality barrier in publications, which must be crossed by those who are honoured. This would provide enough driving force to ensure that the internal competition results in continuous quality improvement with time . The funding agencies are ideally placed to drive this process by ensuring that a minimum quality is demanded and recognised in various ways. A number of initiatives can bring this about.

c.1) Identify Preferred High Quality Journals:

Before initiating any modified practices, it is necessary to define acceptable quality of publications for those who are considered academically top rung. A possible starting point is to have a list of Journals of internationally accepted very high quality. Those who publish frequently in these journals can be considered special. For pure Science, a set of eighty two high quality journals has been prepared by Nature and is available in natureindex.com. Similar set can be prepared by experts for Engineering too. The list of such journals can be reviewed once in five years. These can be considered as " Go To" journals.

c.2) Committee Members

There are a number of high level Expert Committees used by both DST and DBT. As a first step, only those Scientists may be picked up as Members , who have published at least 30 percent (it can be fixed at a different value after proper analysis) of their publications in Nature Index Journals (A minimum number may also be fixed).

Similar criterion can also be employed for selection of PAC Members, who select the projects to be supported. Only those who have a minimum of a given number of publications in the Nature index journals should be considered for Membership of these Committees.

Not only should these experts be themselves publishing in high quality journals, they should firmly believe in high quality.

c.3) High Level Fellowships

A large number of distinguished national Fellowships, Professorships or similar positions are awarded to good research Scientists, who are generally active in research. However, the fund giving agencies must decide whether each one meets the minimum standard of having the requisite number of publications in the NI (Nature Index) Journals. The same criterion must also be used for other important Fellowships like SwaranaJayanti. The same criterion should also be applied while selecting for VAJRA Fellowships, so that the requirement of high quality gets fortified. The basic idea behind these actions is to convey a clear message that quality and not just the number of publications in good professional journals is what the country values. As most of the Scientists working in these elite institutions are having the potential to publish often in these journals, they should receive special attention for the desired quality improvement.

c.4) Project Selection

Both DST and DBT support research in a significant way and much of it is through project mode. They can raise the level of the selected projects so that the publications resulting from them can find acceptance in the NI Journals. It is essential to challenge the fund seekers to the highest level of creativity, as most of them have a considerable amount of unrealised talent. For this purpose, each PI should be asked to indicate how novel his project is and what impact it is likely to make, if successful, giving detailed rationale for his claims. She/he can also be asked to grade novelty into new, original, unusual, revolutionary and unique in ascending order ; and significance into negligible, small, mild, moderate and strong for each of its internal and external components . The committee should discuss this aspect to assess if their self assessment is reasonable and take it into account while awarding the project. The Committee should give preference to those projects which offer higher chances of publications in NI Journals . It should also make sure that the PIs earlier publications are in the top rung journals. High quality can also be ensured for industry related projects by ensuring novelty even if no publications may be expected. If all the involved scientists are

sensitised to better quality requirements, there will be efforts to improve the quality of work, with at least partial immediate success.

c.5) Post Project Follow-up

At present there are presentations on each project at regular intervals but hardly any follow up after the project is over. The performance of the project in terms of publications must be pursued with vigour. If it has not produced any results, there can be restrictions on the PIs further projects unless the committee is completely satisfied with the output.

c.6) Govt. – Industry Fellowships

Many faculty members , after retirement, would like to continue to work. Most take advantage of Retired Scientist or similar schemes. The Govt should provide jointly with Industry special Fellowships to retired scientists to work in R and D sections of Industry. They would thus add to the technical worth of industry, while working in immediately relevant topics of research.

c.7) Centres For Gifted Individuals within Departments

There are many good faculty members but genuinely gifted members are quite rare. Their performance will be way above that of others and so will be their publications. They would be publishing in Nature and Science family Journals more often. Such individuals,who stand out, are unlikely to be more than ten in the whole country. They should be provided centres within departments which they can run with maximum possible autonomy. The Centre can be awarded for a period of ten years initially and special funds can be given to these Centres, if required. Unusually high quality should be the key.

c.8) Identification of Highly Gifted And Creative Students

DST runs the programme KVPY where around 2000 young students are identified for special support including scholarships if they study science. Many of them would eventually end up as faculty in the elite institutions. The selected students are obviously good. However only a few of them would be really gifted. As their selection involves interviews, it is relatively easy to identify those who are not only highly intelligent but also equally creative and committed. Such students should have a special programme of additional training so that their creativity is developed to the maximum possible extent.If some of them take up faculty positions eventually, they could surely raise the level of research and bring excellent name to their institutions.

c.9) Best Publication Awards

Every year, the Govt. should give four or five awards of Rs five lakhs or more for every publication identified as ‘ Best Publication ‘ by a special committee.

c.10) Recruitment Support

These Departments have access to large number of experts, who in turn are aware of potential high quality faculty candidates. Elite institutions manage to attract many of them. However they generally do not locate themselves in universities. Both DST and DBT can help willing universities in recruitment of Faculty and grant starting support to such faculty to start their research activity. The quality of selected candidates should be similar to the ones recruited at the elite institutions.This would have immediate positive impact on the quality of research being conducted at the university.

c.11) Visiting Professorships

The DST has a scheme VAJRA where NRI scientists are invited for a period of three months.To make it more rewarding various institutions should be in touch with the best in quality and persuade them to come rather than asking them to apply. For each of them, there should be a well thought out strategy to generate a mutually beneficial programmes.Apart from lectures there should be regular discussion programmes as well as brainstorming for identifying newer areas of investigation. If possible, longer term associations like collaborative research should be one of the important aims of this exercise. In every case, the minimum quality of the visitor should be ensured to obtain the maximum benefit from the visit.

c.12) Research Initiatives, Multi-centric Projects, Technology Missions

A number of such initiatives have been taken by the fund giving agencies. However upto this time hardly any outcomes have been reported of which an ordinary Indian can feel proud. The main problem arises out of the mistaken assumption that the identification of area is enough. The choice of actual problems is left to the scientists, who may not be able to identify the problems that matter, and hence the quality gets compromised. It is best to have a separate intermediate step of having a number of brainstorming sessions where problems of importance get posed and discussed. Problems thus identified should be offered for solution. Similar approach is necessary for mission projects too.

H.4. Inputs From the Government

There is consistent lament at the relatively low level of support for Research in the Country (generally expressed as percentage of GDP). Comparison is made with many countries where the support is much higher.

Enhanced allocation is very desirable but it should be used in an optimal way so as to obtain some desired outcomes particularly with respect to improving quality of research at elite institutions, substantially enhancing volume of good quality research (similar to the one being conducted now at elite institutions) at not so well endowed universities, and supporting interaction of scientists with Industry through research.

In the elite institutions, the faculty has enormous residual potential which has yet to be unlocked. It is important to raise the quality of research rather than producing more volume at these places. Additional funds should be made available for this purpose.

Providing substantial funds to selected universities can increase volume of good quality research. However, infrastructure does not automatically translate into higher quality research. As quality of research output correlates much better with the people rather than equipment, generous infrastructural support should be provided to those institutions which have managed to recruit excellent faculty, but lack high end facilities. This will result in improved standards and higher volumes in Universities and other less endowed research establishments.

The Govt. should also encourage cutting edge research to be converted to economic activity. Special funds and appropriate mechanism should be established in providing support for scientist – industry interactions. Long term visits by faculty to industrial R and D establishments should be partially or fully supported by the Government. Perhaps more persuasive methods have to be employed to

bring industry and institutions together with the purpose of making the industry internationally more competitive.

A positive ambience is already being generated for startups. As additional encouragement , the Govt. should make such rules that the faculty does not feel hampered and can be permitted to use reasonable amount of institutional infrastructure without incurring any expenditure, when they are trying to translate their research results into economic activity.

Also the earnings from industry either by consultancy or know how transfer should be completely tax free. This will translate into improved selection of projects and more intimate collaboration with Industry.

I. Conclusions

India has enormous reservoir of intelligence and creativity in her well trained faculty present in her elite institutions. Unfortunately, it does not get translated to the highest quality research. Instead *well above average* research is published by the faculty of these institutions in reasonably large volume. However, this good science is not good enough for making a positive contributions to novel ideas in science, improved or new technologies or bringing major benefits to Society. It is surprising as well as disturbing, as India has excellent (elite) institutions of higher learning and enormous demand for admission to them.

Though a number of reasons can be articulated for this lacunae, the most important one involves the indifferent quality of training a student obtains at primary and pre-university levels. It results in an attitude where academic challenges are avoided, students do not get training to solve problems from first principles, and creativity does not get a chance to be developed. It results in faculty picking up problems which are not challenging at the highest level nor do they have any great significance.

In the long run, it will be necessary to pay much greater attention to the foundational education. Immediately however a number of steps can be taken by the faculty themselves, the institutions where they work, DST and DBT and the Central Government. There is also need for assigning greater role to Industry in the R and D scenario of the country.

The emphasis in research has to shift from high volumes to high quality for our country to benefit from the collective contributions from all her scientists and engineers.

R. Kumar,
c/o Department of Chemical Engineering,
Indian Institute of Science,
Bangalore-560012