Restructuring Post-School Science Teaching Programmes

A POSITION PAPER

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Foreword

India's youth are at crossroads today. Their large numbers, their inherent intellectual capability and their desire to contribute to the country's progress characterise the potential in youth power to propel India to a leading position in the knowledge society. However, a major hurdle faced by our youth today is the present state of higher education which frustrates them not only because it fails to prepare a majority of them to be competitively employable, but also fails to excite their young minds. Consequently, their creative energies do not get effectively channelized towards nation building.

Against the background of this paradoxical situation, of being rich in youth power and yet being far from the position of leadership in the knowledge society, it is encouraging that the government and other agencies are today sensitive to the gravity of this situation.

There are strong indications that more liberal funding would become available for revamping the higher education system by not only establishing newer universities, colleges and institutes of learning and research, but also by improving and strengthening the existing centres of higher learning. However, while infrastructure and other material facilities are essential for promoting quality education, how and what is taught at different levels are also equally important. With this in perspective, the three premier science academies of the country, viz., the Indian National Science Academy, the Indian Academy of Sciences and The National Academy of Sciences, India, have jointly discussed this aspect. Following intensive and extensive deliberations amongst their Fellowships, the three Academies have prepared the present Position Paper on the post-school science education in the country.

One of the major causes for the relatively poor state of higher education in science is the compartmentalized curricula and their presentation to students in a fragmented manner. A major reform suggested in the present proposals is to make learning of sciences at post-school level integrative and broad-based so that young scientists emerging through such training are effectively prepared for trans-disciplinary research. In order to reduce the time required for completing doctoral research and to provide for a more coherent and continuous learning programme, the Academies also suggest introducing a new composite 4-year B.S. degree, initially at select centres. This programme would enable graduates to directly enter the professional job market, or to pursue a doctoral degree (Ph. D.) research programme, thus ensuring the much-needed trained research manpower at a pace in keeping with what is obtained in several other countries across the world.

We present this document, on behalf of the three Science Academies, with the hope that the suggestions will be seriously considered by the concerned agencies for their effective implementation.

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Executive Summary

The enormous potential for India to become a leading knowledge power in the coming years can be realized only if our younger generation has opportunities for all-round good education and training, especially in science and technology. Unfortunately, however, the present state of higher education in the country is rather poor. In order to make it more relevant to the changing needs of society and thus to propel India to a position of leading knowledge power, we need massive investments as well as well-planned radical changes in our higher education system. The Science Academies had, earlier in 2006, submitted a detailed proposal to the Planning Commission for investments in higher education in Science during the XI Plan period and modalities for utilization of the resources. The three Science Academies of the country are now proposing changes that are needed in our college and university education in Sciences to meet the emerging challenges.

The major drawbacks of our current post-school science education are: (1) compartmentalized teaching/learning of a few sub-disciplines of science, (2) time and energy wasted in sequential admissions to B.Sc., M.Sc. and Ph.D. programmes, (3) repetition of topics at B.Sc. and M.Sc. levels, (4) poor laboratory facilities and consequent poor training of students in experimental methods, (5) little exposure to research methodologies, (6) limited options for movement between science and technology streams.

Keeping these in view, it is suggested that a new 4-year B.S. programme should be introduced, at select institutions to begin with, which the +2 pass students can join. Subsequently, the interested and competent B.S. qualified students can directly join a dual degree M.Sc., Ph.D. programme. If they wish to leave in between, they can do so with an M.Sc. degree alone. Those qualifying the 4-year B.S. or the ongoing B.Tech can move from basic science to technology and vice versa for further education, leading to M.Sc./M.Tech. and/or Ph.D.

Considering the diversity of students' needs, their interests and capabilities on the one hand, and the varied infrastructure and competence available in the large number of teaching institutions in the country on the other, it is suggested that the existing 3-year B.Sc., 2-year M.Sc. and the integrated M.Sc. or integrated Ph.D. programmes may also continue for the time being.

The +2 qualified students would thus have any of the following options for higher studies in science and technology:

1) 4-year B.S. followed by Ph.D. in basic sciences, with a provision for early exit with M.Sc. degree or dual degrees after completion.
2) 4-year B.Tech. followed by Ph.D. in basic sciences.
3) 4-year B.S. followed by M.Tech./Ph.D. in professional (Technology) field.
4) 3-year B.Sc. followed by 2-year M.Sc. and then Ph.D. or 3-year B.Sc. followed by integrated M.Sc.-Ph.D.
5) 3-year B.Sc. followed by 2-year B.Tech.
6) 5-year integrated M.Sc. followed by Ph.D.
7) Vocational courses.

It is essential that all the existing B.Sc. and M.Sc. as well as the proposed 4-year B.S. programmes follow the semester pattern with credit-based courses. The B.Sc. or B.S. curricula must provide a broad-based learning rather than segregating 'Bio-' and 'Math-' groups very early. In addition, opportunities must be available for students to take at least 15% of credits through courses in other science disciplines and in social science/arts etc. All science courses must have good 'hands-on' laboratory training. The teaching programmes should also include courses in research methodology and communication skills.

There is a strong need for substantial improvement in the quality and quantity of teachers at college as well as university levels. Massive efforts for continuing training of teachers to keep them abreast of developments in science are required. A strong experimentally-oriented science education system would require massive investments for developing the necessary infrastructure in universities and colleges across the country.

1. INTRODUCTION

The unprecedented economic growth in India during the current decade, increasing acknowledgement of the importance of education and knowledge by its large population, and the incremental investments made over the past several decades in expanding the national base of education at all levels, should be expected to provide the necessary impetus for our nation to become a knowledge-leader in the near future. However, as has been widely discussed in recent years, the present state of higher education in general, Science in particular, is far from satisfactory. To actually realize the enormous potential of our youth power, several radical changes are required.

The Science Academies, which represent the best talent in scientific research and education in the country, have been concerned with issues that afflict higher education and research in Science in the country. It is obvious that multi-pronged approaches and strategies are required not only to restore the quality of science education and research but to actually enhance it to continually increasing levels to be internationally competitive.

On the one level, there is an urgent need for a quantum increase in the investments in science education so that our teaching institutions can provide a stimulating and rewarding atmosphere which would be conducive to creative learning. At another level, we need to bring about significant changes in how we train our young minds so that they emerge from their institutions of learning as creative and innovative individuals ready to face the challenge of successfully competing with and taking a position of leadership in the ever-advancing fields of science and technology. It is obvious that the present state of our educational institutions is far from satisfactory to generate the quality and quantity required for the nation to be anywhere near the leading edge. We not only need a large number of new universities and colleges to provide the required increase in quantity of young people trained in different branches of science and technology, but we also need to significantly improve the quality of training.

On an earlier occasion, the Science Academies had deliberated upon the minimal requirements of investments through public funds to improve the “hardware” that would facilitate the desired increase in quantity and quality of trained human resource and submitted their considered proposals to the Planning Commission (please see Appendices I and II). It is clear, however, that mere increase in investment cannot improve the quality. Therefore, the Science Academies also have examined the actual manner of training of the young human resource in science and technology. A Discussion Meeting, jointly sponsored by the three Science Academies, was held at Bangalore on 24 May 2008. This was addressed by the Presidents of all the three Academies and was attended by Vice-Chancellors of several universities, Directors of IISERs, representatives of Directors of IITs, and a large number of science educationists and researchers from different parts of the country. A large number of them participated in the day-long discussions. The present report has been prepared on the basis of these extensive discussions.

2. THE EXISTING BASIC SCIENCE TEACHING PROGRAMMES

A student enters the science stream of learning during the later part of school education, the +2 stage in the current pattern. The state-funded higher secondary education system, although in need of much improvement, has nonetheless contributed significantly to the volume of students receiving their higher secondary (10+2) certificate with basic sciences as major subjects.

The most common pattern prevalent all over the country for post-school (10+2) teaching programmes in basic sciences requires the students to go through a 3-year B.Sc. course followed by a 2-year M.Sc. course before they can join a Ph.D. programme.

The B.Sc. programmes offered in different central/state/private universities have several variations. Most of them follow the annual system, although a few have switched over to the semester pattern. The B.Sc. (pass) degree typically involves study of a pre-defined combination of three subjects in all the years, although in some cases during the third year of B.Sc., only two subjects, out of the three studied earlier, are taught. Several universities offer Honours at B.Sc.: in this case, the student studies a pre-defined set of three subjects in the first two years and only one subject in the third year for Honours (or Major) in that subject. In some universities, the Honours subject is defined in the first year of B.Sc. itself such that the student studies three subjects all through the three-year course but with greater emphasis on the subject chosen for Honours. In yet another variation, some B.Sc. degrees involve study of only one subject all through the three years.

In most of the universities, the three-subject combination at B.Sc. is compartmentalized among three major science streams, viz., the 'Bio' (or 'Medical') group, the 'Maths' or 'Physics' (or 'non-Medical' or 'pure science') group, or the 'Geo' group, with little freedom for the students to learn across these groups. For example, those opting for 'Mathematics' or 'pure Science' stream, study Physics, Chemistry and Mathematics or Statistics or Computer Science but nothing of Biology while those opting for the 'Biology' stream cannot study Physics, Mathematics, Statistics or Computer Science etc.

On completion of the B.Sc. degree, the student seeks admission to the 2-year M.Sc. (annual or semester) often with a specialization in the final year. A majority of the M.Sc. courses are also confined to one subject only, with the possibility of a student opting for a particular branch within the subject as 'special paper' or 'major elective'. Barring a few cases, there is hardly any avenue available for students to learn something outside the subject in which they qualify for the M.Sc. degree. In most cases, there is only a little component of research in the M.Sc. curricula.

Some institutions have also started integrated M.Sc. – Ph.D. programme for B.Sc. degree holders, with a provision for graduation with M.Sc. degree after successful completion of the course work.

The newly instituted IISERs and a few other universities/colleges have, in recent years, started 5-year integrated M.Sc. programmes in which the student gets admitted after the +2 stage. These courses are better organized in terms of the broad-base and flexibility of course combinations that a student can choose from. These courses provide scope for some 'hands on' experience of research.

For a variety of reasons, most of the existing B.Sc. programmes provide only little of actual laboratory exercises and little scope for any exploratory ("soft" research) activity on the part of the student. Consequently, students hardly learn "how to practise science".

3. LIMITATIONS OF THE PRESENT SYSTEM

In terms of our present structured (school to college to university) education system, the undergraduate science education (B.Sc.) is expected to:

1) prepare students to take up an academic/professional career requiring more specialized learning/training at the post-graduate level. This stream is expected to provide the pool of well-trained teachers/researchers and thus the B.Sc. degree is to be followed by M.Sc., which for those desiring to pursue a career in teaching at higher levels and/or a career in research needs to be followed by Ph.D.

or

2) provide training to students so that they may find gainful employment (self- or otherwise) – B.Sc. may be a terminal degree in such cases or may require a diploma in specific field/vocation.

In recent years, a substantial increase in the number of students at the higher secondary level, resulting from the much-desired awareness for learning and also because of growth of the country's population, has led to a mushrooming of privately run schools. The generally poor funding of state-run schools on the one hand, and a lack of rigorous monitoring, and the unwillingness of the management of private schools to reinvest in the system on the other, have been detrimental to quality education at the higher secondary level. The science stream of school education has suffered the most due to these factors. Another drawback of the science education curriculum at 10+2 level is its highly compartmentalized structure into the Physical Sciences and Biological Sciences streams. A student of the former category can graduate by studying only mathematics, physics and chemistry as science subjects, along with one language course and one additional subject which could be, for example, physical education. Similarly, for a student of the Biological Sciences, the common choice is to go for biology, chemistry and physics with any additional subject and a language course. The biology students do not study mathematics and vice versa. Moreover, in recent years, specialized subjects such as biotechnology, bioinformatics, information technology and computer science etc., are being introduced as substitutes for the fundamental subjects like biology, physics or mathematics. This practice is hollowing the foundations of a core science education. Instead of introducing these specialized courses, the need of present times is to ensure that students learn all basic courses of science, viz., physics, chemistry and biology, in addition to mathematics. This would enable them to adapt to the changing scenario of science education in which the rigid disciplines of the past are diminishing rapidly.

The avenues of higher education available to these school science graduates of the country to continue in S&T, whose numbers run into several lakhs per year, fall into several categories such as:

1) A four-year professional course in engineering (B.Tech./B.E.) offered by IITs, NITs and the state and privately run colleges.
2) A four and a half-year (+ 1 year internship) medical degree (M.B.B.S.) offered by the central, state and private medical colleges.
3) A five year Master of Science (M.Sc. or M.S.) course offered by some of the IITs, all IISERs and a few central/state universities.
4) A three-year Bachelor of Science (B.Sc.) course, usually with a clear bifurcation of physical science and biological science streams, offered by central and state universities and a myriad of colleges. This is followed by a 2-year M.Sc..

While a small fraction of the graduating higher secondary students get the opportunity to avail option #1, or #2, and still fewer the option # 3, a majority of them either drop out of a career in S&T or go for option #4, which culminates in a B.Sc. degree. However, the poor structure of B.Sc. programmes, compounded by poorer teaching and facilities, fails to prepare the students for a gainful employment or launch a promising academic career. This, combined with the unprecedented demand for engineering, and to some extent for medical graduates, is steering a large number of higher secondary science students to take option #1, although only a fraction of them actually succeed. More unfortunate, however, is the fact that a majority of those who succeed in this option actually end up in private engineering colleges, which have mushroomed all over the country but have very limited facilities and capabilities. Obviously, most of these institutions do not offer a meaningful engineering/medical education. Thus a large proportion of students graduating from such engineering colleges face great difficulty in finding employment even with much lower remuneration than those graduating from the established seats of learning such as the IITs and NITs.

The present system of science education at post-school level thus fails to fulfil the basic objectives because:

- It does not provide a holistic learning of sciences due to paucity of time and rigid course structure;
- the compartmentalized learning does not adequately prepare the student, either for research or for pursuing a career requiring general skills in science;
- In most institutions, the student is required to select the honours/ major subject at the time of joining a B.Sc. programme before realizing his/her real interest in the subject;
- there is little training of young students in methods of scientific enquiry;
- there is almost complete neglect of Humanities in most of the B.Sc. curricula across the country;
- Lot of time is wasted every year because the actual teaching time is just about 6 months a year. The summer months are rarely utilized in a meaningful manner. Further, after finishing B.Sc., the students waste about 6 months in securing admission to M.Sc. (often after writing yet another set of entrance examinations);
- the Master's course that follows the B.Sc. programme significantly overlaps with B.Sc. curricula, which makes the students disinterested;
- Typically 10 or more years are required after school to get Ph.D. This makes the choice of a career in science less attractive to young children and their parents, because other fields provide more rapid employment opportunities;
- The switchover from science to technology/engineering and vice versa is generally not possible due to the unequal durations of B.Sc. (3 years) and B.Tech. (4 years) programmes.

While the above problems stem partly from poor pedagogy and poor infrastructure at the colleges/universities, a major part relates to the way our teaching programmes are structured.

The rigid bifurcation insisted upon at the first non-professional science degree course (B.Sc.), is severely limiting the competence of our country's science graduates in the current global scenario of interdisciplinarity. An extreme of this compartmentalized education is the introduction of specialized courses like those in biotechnology, genetics, bioinformatics, nanotechnology etc., at B.Sc. level. In most of these programmes, the students hardly learn the basic science part and thus remain incompetent for basic as well as technological applications.

It is clear that the contemporary cutting edge questions in life sciences cannot be solved without knowing the concepts, tools and techniques employed by professional physicists and chemists and without developing adequate computational and mathematical skills. It becomes extremely difficult to demarcate specific subject boundaries in many emerging areas of science and technology, like those in smart materials, nanomaterials, micro (molecular) electronics, biotechnologies, biosensors, etc,. More broadly, it is difficult to distinguish between electronics and physics, materials science and chemistry, and between biology and biomaterials. Without understanding the basics of one field, it is no longer possible to exploit the possibilities offered by another. One of the major reasons for the relative poor innovative R&D activity in the country indeed is the lack of in-depth interdisciplinary teaching and the required level of flexibility in moving from one discipline to another.

4. COUNTRY NEEDS FLEXIBLE AND MULTI-CHOICE HIGHER EDUCATION SYSTEM IN SCIENCES

In view of the great diversity of socio-economic, cultural and political structure of India, it is not possible to meet the highly varied educational requirements of its increasing numbers of youth through any one system of course structure. It is clear that India contributes substantially to the pool of youth in the world and its share will increase in coming years. To harness this enormous potential in youth power, it is essential that we prepare our new generations well to meet the existing and emerging challenges so that not only are their aspirations satisfyingly fulfilled but the country as a whole can indeed become a knowledge power.

The rather monolithic structure of our current under-graduate and post-graduate teaching programmes has failed to prepare youth with qualifications required even in current times. This failure would only magnify in coming years unless our education system is radically and urgently changed to provide the much needed flexibility as well as integration.

There are varied ambitions and reasons for a student to seek admission to the science stream at post-school level. It is unfortunate but true that a majority of students enrolling for a B.Sc. degree across the country do so because they failed to get into a professional stream. Only a small proportion joins the B.Sc. programmes by choice. If our B.Sc. teaching programmes were really challenging and better organized, many of those who initially drifted into this stream without a choice, would subsequently begin to enjoy what they are studying and thus turn into creative individuals. Unfortunately, the present dispensation often frustrates even those who came to this stream initially by choice.

Any change in the existing archaic system of science education must take into consideration the diverse requirements of the aspirants as well as the highly disparate capabilities of the range of academic institutions that are engaged in imparting such education.

The students' expectations can be broadly grouped into the following:

1. Most students who join the science stream as under-graduates are neither willing to nor capable of finally taking up an academic career (R&D and/or teaching). For a large number of students, the Bachelor's degree would be the terminal degree and therefore, it should prepare them to earn their livelihood respectably, through jobs (private or public), business etc.
2. Those who wish to choose science as a career (moving into R&D activities and/or teaching or science administration) need to go for Ph.D.
3. Appropriate vocational training courses should be available for those holders of Bachelor's degree who are inclined to be vocationally creative.

The range of academic institutions is also very wide in terms of expertise and capabilities of their academic and other support staff on the one hand, and available facilities and funds on the other:

1. Some research institutions have highly competitive and accomplished faculty and good infrastructure. However, while most of them have Ph.D. programmes, only a few have PG programmes and almost none of them are involved in UG teaching.
2. The newly established IISERs and the IITs or NITs are better endowed in terms of infrastructure, faculty and academic/administrative autonomy.
3. Several of the central and some of the state university departments have long-standing programmes of UG and PG teaching; however, the quality of infrastructure and faculty is, by and large, not up to the required level. Many of the central universities offer only PG and Ph.D. programmes, while some also offer UG programmes in their science departments. Each university has different sets of rules and regulations but the individual departments do not have the desired levels of academic autonomy.
4. The many state universities provide affiliation to large numbers of colleges scattered around the geographical area of the given university. These colleges have a wide range of infrastructure capabilities, ranging from very poor to tolerable, but they are bound by the common academic and administrative procedures defined by the affiliating university. In addition, depending upon the geographic locale, e.g., urban vs rural or semi-urban, the overall quality of facilities and capabilities also varies, although the student population, in terms of their academic capabilities, need not vary in the same proportion.
5. A large number of colleges (imparting UG as well as PG education) have been recognized by the UGC as autonomous colleges. They have some degree of academic and financial autonomy although their degrees carry the name of an affiliating university.
6. A large number of institutions (private as well as public) have been recognized as "deemed to be university" or private university. They enjoy considerable autonomy and often can develop good infrastructure but in the absence of the required level of academic audit, the quality of education imparted at many of them is below the minimal expected levels.

The categories 4-6 contribute maximally to the pool of graduates produced in the country. Given the wide disparities between different types and centres of learning and the varying requirements of the students, it is obvious that no one pattern can meet all the requirements. We need to provide for different programmes that cater to different needs and can be imparted by institutions of varying capabilities. There has to be a greater degree of autonomy and flexibility with a more powerful and vigilant performance audit of the institutions.

5. PROPOSAL FOR INTRODUCTION OF A 4-YEAR POST-SCHOOL B.S. PROGRAMME FOLLOWED BY PH.D.

Keeping in view the above considerations and following extensive discussions, the Science Academies are of the view that the country needs to introduce a **Four-year B.S. programme** following which, the successful graduates can directly join Ph.D. programmes. Some of the obvious advantages of the 4-year B.S., which provides eligibility for enrolment into Ph.D. programmes, are the following:

- Compared to the 3+2 years of B.Sc. and M.Sc. programmes, a continuum of 4 years provides for better time-management for teaching in a holistic manner. This would permit a broad-based training (including in humanities or other fields of individual choice) of science graduates, which is essential for developing a true knowledge society.
- Students (and parents) do not need to worry about one more entrance test and they may have better options for jobs after 4 years than after 3+2 years under the present system.
- The 4-year B.S. programme has international equivalence and many of the bright young students, who opt to study abroad because of the reduced time and greater flexibility, would find it equally good within the country and this would reduce “brain-drain”.
- Since the B.Tech./B.E. courses are of 4 years’ duration, the 4-year B.S. programme would facilitate the possible switchover from science to technology/engineering and vice versa.
- Any deficit in the 4-year programme in relation to Ph.D.- related research can be taken care of in the course work for Ph.D.

- In the short term, such a 4-year B.S. programme may be a high quality preparatory first part of a research programme leading to a Ph.D. Over a longer term (say 10 to 15 years) it can replace the present 3-year B.Sc and be regarded as being as attractive as a B.Tech, because such graduates may have wider employment opportunities on account of much better training in science.

6. FLEXIBLE AND MULTI-CHOICE UG AND PG SCIENCE EDUCATION PROGRAMMES

While it is widely agreed that a 4-year B.S. programme offers a better, and therefore, preferable pattern, it is also clear that given the above noted wide disparities and local constraints, the country should have multiple models for post-school science education so that prospective candidates can choose what they prefer from amongst those available. Accordingly, the following multiple modes are suggested:

1. A new 4-year B.S. programme which permits entry to Ph.D. programmes, without the need for a Master's degree;
2. The existing 3-year B.Sc. + 2-year M.Sc. + Ph.D.;
3. Integrated or dual-degree Ph.D. programme for the 3-year B.Sc. degree holders;
4. The 5-year Integrated M.Sc. programme (as in some universities and IITs and in IISERs) for the +2 qualified students followed by Ph.D.

The following provides some general guidelines about each of the above programmes.

1. The four-year Bachelor of Science (B.S.) programme (new proposal)

1. Those passing out of the +2 level in science stream will be eligible for admission. On successful completion of the 4-year course, they would be eligible for seeking admission to Ph.D. programme, since it is expected that the 4-year period would prepare them as well as or better than the conventional 3-year B.Sc. + 2-year M.Sc. courses

and any deficit can be made up by course work during Ph.D.

2. The B.S./B.Tech. degree holders can switch over to Ph.D. in areas of science different from their Major/Honours subject as well as in Engineering/Technology if they qualify in the relevant tests etc.
3. The B.S. programme would be a credit-based semester system in all engineering/science colleges/institutions.
4. B.S. students will opt for a Major subject in the last two years.
5. There should be transfer of credits from within and between institutions.
6. Students in final year of B.S. should be eligible for NET and equivalent tests.

The common core courses during the first four semesters should cover basics in:

- Mathematics
- Physics
- Chemistry
- Biology
- Earth Sciences
- Humanities and Social Sciences
- Computing skills
- Communication skills
- Workshop practices
- Laboratory practices

Subsequently, the B.S. students would acquire substantial knowledge/skill in one subject (Major) and get additional training in at least one more subject (Minor). The students would be exposed to research early on, through term papers and projects.

It is important to emphasize that everything need not be taught and the basic philosophy should be to arouse the curiosity of students and encourage them to undertake projects on various topics. Emphasis should be on learning and research. Overall, there should be a multi-disciplinary training.

Additionally, it is very important to have courses which inculcate a sense of societal responsibilities, a spirit of teamwork and innovation, and leadership qualities. Programmes such as NCC, NSS, sports, outreach and lectures on history of science are ideal to achieve these goals. In addition, a critical and balanced approach to an account of the Indian Heritage in the sciences, mathematics and technology, accompanied by an appreciation of our art, literature and culture, need to be developed and communicated to students.

A general model for distribution of credits in different subjects during the 8 semesters of this programme is given in Appendix III. Appendix IV provides further suggestions/explanations about the proposed 4-year B.S. programme.

Ph.D. programme following the 4-year B.S.

1. The first year of Ph.D. should be largely devoted to course work (deficit courses as well as advanced course in the specific area of research), with the combination of courses being selected in consultation with an Advisory Committee;
2. Completion of Ph.D. would entitle the candidate to get a dual degree: M.Sc. as well as Ph.D.;
3. Those who wish, may exit with an M.Sc. degree after successful completion of course work and a dissertation;
4. B.S. and B.Tech. can be equivalent for crossover for Ph.D. in science and technology/engineering;
5. Flexibility to be provided for time required for completion of the course work and for selecting combinations of courses;
6. It is desired that each doctoral candidate publishes at least 2–3 original research papers in peer-reviewed journals prior to submission of the Ph.D. thesis.

Restructuring of the existing three-year B.Sc. and 2-year M.Sc. courses

In view of the diversity of needs of students and the capability of teaching institutions, it is desired that the existing 3+2 pattern of B.Sc. and M.Sc. courses may also continue for some time. However, as discussed earlier, these courses need to be restructured to provide integrated learning, rather than making the students specialise too early without being adequately exposed to the basics. Therefore, the following measures, which can be implemented by institutions ranging from those with limited infrastructure to those which are better endowed, are suggested in order to improve the quality of teaching and learning in the conventional B.Sc. and M.Sc. courses

1. Semester system: A semester system with internal class assessment (30–50%) followed by end-semester examinations (70–50%) should be followed since credit-based courses allow flexibility in combinations that a student may select out of several possibilities.
2. First year of the three-year B.Sc. programme should include courses in all major disciplines of Sciences, so that all students learn the basics of 'physical', 'life' and 'earth' sciences. These courses should advance the student's understanding beyond what is expected to have been learnt at the +2 level. 'Deficiency' courses may need to be planned for those who may not have studied Mathematics or Biology at the +2 level.
3. In the second year, a student may select three main subjects; however, about 15–20% of credits should be earned through courses from other streams (e.g., a student of 'Physics/Maths' stream may take some courses in Biological/Earth sciences and vice versa).
4. During the third year, a student may select one subject (Major or Honours subject) out of the three studied in the second year. Again, 15–20% credits should be obtained through courses in other streams. These should also include courses designed to improve "skills" like computer programing, statistics, instrumentation (optical/electronic) etc.
5. 'Interdisciplinarity' should not be at the cost of 'classical' concepts in any of the core subjects, which need to be identified and carefully included.
6. The course contents (and teaching) should be geared to develop concepts rather than merely provide 'information' for memorizing.
7. The field of biology has expanded enormously in the last few decades and will continue to expand for a few more decades. The perceived potential of several of the so-called 'modern'

areas in Biology has led to introduction of specialized courses like biotechnology, bioinformatics, genetics etc., at the under-graduate level as well. However, in the absence of integrative learning of basics of biological systems and adequate laboratory work, such courses, in general, produce large numbers of graduates with little knowledge, and therefore, mostly unemployable. Therefore, B.Sc. degrees in such specialized subjects (e.g., biotechnology, bioinformatics, genetics, nanotechnology etc.) must be stopped.

8. All science courses must include 30 to 40% credits in laboratory and field work (where applicable as in Earth sciences and some areas in Biological sciences) and the laboratory exercises should be planned in such a manner that students have opportunities for 'hands-on' training, and a certain proportion of practicals should be 'open-ended' so that students can learn to be innovative/ exploratory. The 'open-ended' exercises may also be in form of 'projects', which should include, besides actual study, preparation of a formal report. Care must be exercised to ensure that the practicals do not become 'rituals' or 'demonstrations', and project reports do not get 'copied' from one batch to the next. Adequate laboratory facilities and competent teachers are essential to ensure student's continued interest in learning and practising science.

9. It is also desirable that all students learn language, at least from the viewpoint of presentation of data etc., in scientific reports/papers. In addition, the students should be encouraged to take some extra credits through courses in history of science in ancient and modern India, and/or in fields of Arts, Social Sciences, Performing Arts etc to help develop a more integrative personality.

10. To encourage communication skills, each student should be required to give at least one seminar on a current topic in the third year of B.Sc.

11. The M.Sc. courses should also be semester- and credit- based and should include ~15% credits through courses outside their main subject. Depending upon the available expertise and facilities, special papers or major electives may be offered. The laboratory exercises must involve hands-on training rather than only demonstrations. Further, to inculcate the habit of asking questions and interpreting

data, several of the experiments conducted by M.Sc. students must be "open-ended" which do not have a pre-defined result.

Integrated B.Sc. – M.Sc. course (5 years)

1. In many situations, it may be desirable to have a 5-year integrated M.Sc. course in which students enrol after +2 direct for the M.Sc. degree. Such Integrated courses have the advantage of maintaining continuity from one level to another thus avoiding lots of repetitions that happen in the two separate degree programmes. The time thus released can be effectively used for more wide-based learning and some research experience.
2. The Integrated courses should be allowed only in University/ College departments which are really active in research so that the students are exposed to quality laboratory exercises and research environment from first year onwards.
3. As suggested for the regular B.Sc. (and M.Sc.) courses, the Integrated programmes must follow semester system with wide-based curricula and sufficient flexibility in selection of courses by individual students, keeping in view their own likings/deficits etc.
4. Appropriate provision may need to be provided for exit, at the end of the third year with a B.Sc. degree, to those students whose cumulative grades are below a certain point (e.g., equivalent to 60%) or for those who do not wish to continue to get M.Sc. degree and feel that B.Sc. may be their terminal degree. This will ensure that only those serious about higher studies continue to get M.Sc. Likewise, a provision of 'lateral entry' of bright students who completed a regular 3-year B.Sc. degree into these M.Sc. programmes also may need to be made.

Integrated Ph.D. programmes

1. Institutions with good research capabilities may offer integrated or dual-degree Ph.D. programmes for students who have successfully completed the 3-year B.Sc. programme. The course work, equivalent to 3 semesters (i.e., ~15 courses), should provide advanced learning broadly related to the field of study and deficiency courses, if required.

2. Option may be provided for exit, with M.Sc. degree, after successful completion of the 2 years of course work and a research project.
3. Flexibility in time required for completion of a degree and in combinations of courses to be provided.
4. It is desired that each doctoral candidate publishes at least 2–3 original research papers in peer-reviewed journals prior to submission of the Ph.D. thesis.

Technology/Engineering courses for 3-year B.Sc. degree holders

1. The 3-year B.Sc. graduates, who do not wish to pursue an academic career but have an inclination for technological applications, may join a 2-year B.Tech./B.E. programme. This will enable them to meet a variety of requirements in industry, defence and educational institutions where scientifically trained technical personnel are needed.
2. B.Sc. graduates with a strong science/mathematics background would be ideal for a two-year B.Tech. in computer science and engineering, electronics and communications engineering, biomedical engineering, biotechnology etc.

Vocational courses

1. Appropriate vocational courses may be designed and introduced in areas that can provide direct employment. This may be based on a good analysis of local industrial and other requirements. Some general examples are: (i) Bio-Medical Laboratory Techniques; (ii) Bioinformatics; (iii) Biotechnology, (iv) Computer Applications (Hardware and/or Software); (v) Electronics, (vi) Laboratory Techniques (for Physics/ Chemistry labs) etc.
2. In addition to the above, the various vocational training courses offered by the ITIs also need to be strengthened and diversified so that those getting trained in such courses can find meaningful self-employment.
3. These courses need to be so designed that the students may be

ready for gainful employment. These courses may be available to students after school (+2) or after 3-year B.Sc. or the 4-year B.S. depending upon the nature and level of training and should provide a diploma certificate.

Summary recommendations

In summary, as shown in the flow diagram in Figure 1, it is suggested that the following multiple options should be available to a student coming out of school through science stream:

1. 4-year B.S.
2. 3-year B.Sc.
3. 5-year integrated M.Sc.
4. Admission to Ph.D. after 4-years of B.S. or B.Tech., with a provision for early exit with M.Sc./M.Tech. degree, or dual degrees after completion.
5. Admission to Ph.D. after 3-year B.Sc. followed by 2-year M.Sc.
6. Admission to Ph.D. after 5-year integrated M.Sc.
7. Admission to Integrated Ph.D. after 3-years of B.Sc. (M.Sc. degree can be given along with the Ph.D. degree).
8. Admission to vocational courses immediately after passing out from school or after Bachelor's degree.

7. IMPLEMENTATION

While it may be desirable to have a uniform pattern of post-school education in the country, it is obvious that given the diversity in the needs of different students and the capabilities of different teaching institutions, a uniform pattern would fail to deliver the qualities of graduates required in different fields. Therefore, the different programmes suggested above may continue, for the time being, in parallel.

Some general suggestions in this regard are as follows:

The suggested 4-year B.S. programme must be introduced initially at only those institutions which have good ongoing research, PG and

UG teaching programmes so that they can develop a good academic programme without major hurdles.

The large number of ill-equipped colleges spread across the length and breadth of India would find it difficult at this stage to implement the 4-year B.S. programme and to deliver the required level of excellence. Therefore, the 3-year B.Sc. programmes with reorganized broad-based curriculum, should continue at these institutions. The better endowed university departments should take a collective responsibility to provide opportunities of higher learning to the students graduating from such colleges. While some of these institutions may continue or initiate integrated M.Sc.-Ph.D. programmes for the 3-year B.Sc. graduates, others may continue with separate M.Sc. and Ph.D. programmes, as existing. However, the 4-year B.S. programme may be introduced at all institutions over the next 10 years.

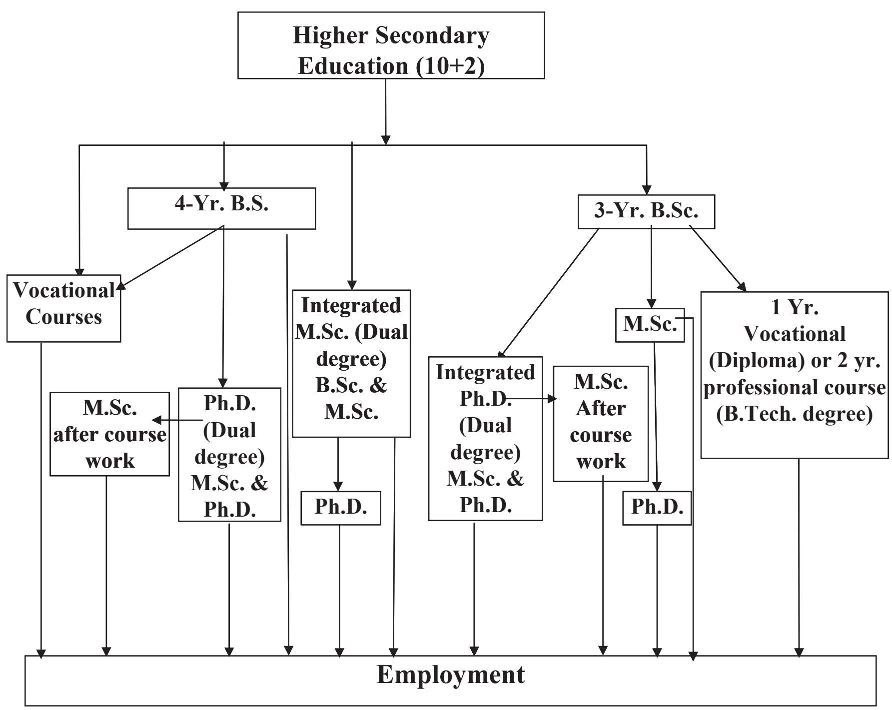

Figure 1. The suggested multiple options available for a student coming out of 10+2 schooling with science stream

The 4-year programme will be at variance with the present minimal requirement of M.Sc. qualification (five years post +2 school level) for most governmental and university teaching positions as well as scientific positions in various organizations like DAE, CSIR, DRDO, ICMR, ICAR, ISRO etc. This would raise the question of equivalence of these degrees for employment. It is expected, however, that a provision for exit after the course work from the dual-degree Ph.D. programme with an M.Sc. degree should provide an opportunity to those who seek employment with an M.Sc. degree rather than after the Ph.D. degree.

Necessity for teachers' training and better pedagogy

It is obvious that any learning programme depends heavily on the understanding of the teacher and methods of teaching. With continuing rapid advances in different fields of Science, it becomes essential that the teachers not only keep themselves abreast with these developments but also be able to excite young minds so that they become more imaginative and creative. In addition to the need for self-learning by teachers, there is a need for organized training to update their knowledge, understanding and application of newer developments.

A major limitation of teaching of science in our universities/colleges is the general absence of even basic laboratory exercises. To reverse this situation it is necessary not only to allocate enough time for laboratory work but also to improve the facilities and to design and develop simple experiments (including open-ended ones which stimulate analysis and thinking on the part of students) which are doable even in remotely located colleges etc.

8. CONCLUDING REMARKS

Much of our current education system seems to be contrary to the basic philosophy of education that teaching is not a process of filling an "empty vessel" with information and that the learners are not passive recipients of "ready to use" packages of information. Education or teaching is a bidirectional interaction between the teacher and the learner.

The great philosopher and statesman Sarvepalli Radhakrishnan stated "to help the students to earn a living is one of the functions of education, *earthakari ca vidya*". However, he further says "Education, according to the Indian tradition, is not merely a means of earning a living .... It is initiation into the life of spirit, a training of human soul in the pursuit of truth and the practice of virtue ...... all education is, on the one side, a search for truth; on the other side, it is pursuit of social betterment". Therefore, he commends "Education should give the children not only intellectual stimulation but a purpose" and "any satisfactory system of education should ..... insist on both knowledge and wisdom, *Jnanam vijnana-sahitam*. It should not only train the intellect but bring grace into the heart of man".

Shri Aurobindo highlighted three basic principles of the teaching-learning process:

1. Nothing can be taught – the teacher is not an instructor or task-master, he is a helper and a guide;
2. The mind has to be consulted in its own growth – the idea of hammering the child into the shape desired by the parent or the teacher is barbarous and ignorant superstition;
3. The teacher should work from the near to the far, from that which is to that which shall be.

We need to follow these basic tenets of education. Only then will our new generations of students graduate out of their learning institutions full of knowledge and with the capability to analyse and creatively use that knowledge.

* * * * *

Appendix I

MEETING CHALLENGES IN HIGHER EDUCATION AND RESEARCH & DEVELOPMENT

Recommendations of the Indian National Science Academy (New Delhi) and the Indian Academy of Sciences (Bangalore) to the Planning Commission for the XI Five Year Plan

India faces enormous social challenges as well as opportunities for rapid development in the new millennium. Our unprecedented recent economic growth, the values of knowledge and education shared by a billion diverse people, and the investments made over the last half century, all point to India's potential future as a knowledge economy with high level man (and woman) power in the science and technology driven global village. Other countries visualizing a similar future, are investing massively to improve both the quality and quantity of higher education and research, some to give their societies a competitive advantage, and others to preserve their advantage. India has suffered in the past because of severely suboptimal investments in these areas. The present juncture is critical for Indian science: major positive steps would enable it to flower and play a key role in taking India to a leading position in the future, but inaction or sub-optimal action would accelerate the national decline.

Given this background, the Indian National Science Academy (Delhi) and the Indian Academy of Sciences (Bangalore), as representative bodies of leading Indian scientists (in the broadest sense of the term), are strongly of the opinion that concrete action needs to be taken urgently in science-based higher education and research and have jointly prepared a set of proposals and recommendations for the XI Plan. These proposals, if accepted and implemented, will improve higher education, give a fillip to R&D and will make India more competitive globally. These recommendations have been prepared after very wide consultations and reflect a broad consensus.

This report is focused on increasing and improving the 'supply side' of the scientific and technological community. However, a major change is needed to attract a large number of young Indians to science-based careers, the Academies will bring out within a year, a document which describes authentically and in detail the various opportunities present and future in this large and central area. These opportunities could be in existing institutions, in research and development, in new institutions, in the industry as well as in new areas where we have advantages and potential for competitive growth, e.g., bioengineering and biotechnology, pharmaceuticals, nanotechnology, etc. This is a necessary complement to the public investment proposed here. It will help to sensitize the society at large to the possibilities, which such an investment will help realize.

For the preparation of these recommendations, besides the views of the Academy members, findings and recommendations of the following Committees and interactive symposia were also taken into consideration:

- India Science Report (Science Education, Human Resources and Public Attitude towards Science & Technology), Indian National Science Academy, 2005
- Report of the Committee constituted by SAC-C to examine and recommend a New Science Education Initiative from 10+2 onwards, 2004
- 'Attracting Young People to Careers in Science', a seminar organized by the Indian Physics Association, The Office of the PSA to GOI, IIT - Delhi and the Nuclear Science Centre, New Delhi, 2005
- The National Conference on 'India's Competitiveness and Preparedness in Science and Technology for the coming decades - Issues, Challenges and Strategies' organized by the National Institute of Advanced Studies and JN Centre for Advanced Scientific Research, 2005
- Report of the Task Force for Basic Scientific Research in Universities set up by the MHRD, GOI, 2005
- Recommendations of the Third Conference of Central Universities' Vice-Chancellors, January 2006

The main thrust of the recommendations is to facilitate development of human resource that is capable of utilizing available knowledge to create wealth and of generating new knowledge and innovations. This is sought to be done by improving the higher education and research profiles of universities and institutes.

The Prime Minister, Dr. Manmohan Singh, spelt out succinctly the challenges nd directions for our future as a knowledge economy while launching the Knowledge Commission last year. He said “At the bottom of the knowledge pyramid, the challenge is one of improving access to primary education. At the top of the pyramid, there is need to make our institutions of higher education and research world class. – . The time has come for India to embark on a second wave of nation building. –. Denied this investment, the youth will become a social and economic liability.”

Worldwide, Universities continue to play a very vital and critical role in the development and evolution of societies. Universities educate young minds and create aware and dynamic citizens. But much more than this, universities generate new ideas and encourage innovation. A vibrant democracy like ours, wedded to the ideas of pluralism, secularism and inclusion must have universities, which not only cherish these values but also actively promote and nurture them.

Currently, higher education is drawing tremendous attention in both developing and developed countries. In the developed countries the emphasis is on maintaining their edge in innovation and generation of knowledge. To maintain their competitive superiority, the developed countries are investing heavily in R&D both in the private as well as the public sector. It is worth noting that even a country like the USA, which remains the leader in Science & Technology, is investing substantially in science education at all levels to encourage its younger generation to take to science as a career so that it can maintain its leading position. These countries with their wealth of resources will also continue to attract the best talent from all over the world to their universities and industry to maintain their competitive edge. This one-way flow of the best from the developing to the developed countries will only increase in the future due to the ageing demography of western societies.

Amongst the countries which have more recently moved from a developing to a developed status, strengthening of the education system, emphasis on R&D and training of professional managers have been the key ingredients of success. Countries like China have made substantial increases in their allocation of resources for higher education. In the first phase of their scheme for improving higher education, China has provided a grant of US $125 million to each of the 10 leading Universities and US $225 million to Beijing and Tsinghua Universities. In the second phase additional grants will be provided to 30 Universities with the overall aim of having 100 quality Universities in China in the 21st century and with 15% of its citizens in the age group 18-22 receiving tertiary education.

India cannot remain behind. In addition, with both the Services and Manufacturing sectors on the upswing, there will be a growing demand for qualified human resource.

At this point it is desirable to explicate the reasons why we believe that substantial public investments of the kind outlined below are urgently necessary. At our present stage of growth, where there is increasing international pressure for knowledge based, value-added development of major areas like pharmaceuticals, drugs, biotechnology, nanoscience/technology, healthcare, genetics, information/computer technology etc, it is clear that both in terms of numbers and quality, a vast expansion and intensification of higher level education embedded in research is essential. This situation is different from the felt need for expansion in professional education and training, which has indeed been met in many ways during the past decade or two. The first non-professional degree (viz., B.Sc.) by itself is, unlike professional degrees, of not much value or societal attractiveness unless it is of educationally good quality, obtained in a lively research environment, and is supplemented by a professional edge (e.g., additional skill building that adds to employability) or research experience. We make several suggestions about how to achieve these. Of the large number of such people with a first degree, a small fraction (typically a sixth) go on to higher degree or research; the remainder, if well trained, add to the knowledge economy in a wide variety of ways. Given the large numbers, their less defined employability and the long gestation period, it is universal practice to have massive public investments for ensuring their quality so that they effectively contribute to a knowledge economy. Our country has, however, invested much less by international standards. Following the first wave of nation building, the more recent investments have been largely concentrated on relatively small, specialized and primarily research oriented institutions. At this stage, we need a second wave of nation-building. If we embark on this fully, not only will there be a large number of skilled, well-trained, capable, flexible scientific knowledge workers needed both by our economy and by the world, but there will also be a remarkable flowering of research (and development). We must seize this opportunity since otherwise, in the intensely competitive, globalized environment of today, we will at best be spectators, perhaps victims, but not participants.

We recommend the following proposals for Universities and Institutes to improve the quality of higher education in India. Some of these recommendations, as may be expected, are similar in spirit to those made by a committee of SAC-PM under the chairmanship of Prof. M. M. Sharma for rejuvenation of basic research in universities and by other committees recently setup by the Planning Commission. The report of this committee has been accepted and it has been empowered to give effect to its recommendations, although action on the ground is still awaited.

We emphasize that the suggested enhanced quantum of support for teaching and research in Science & Technology during the next Plan can be meaningful only when matched by major administrative and financial reforms in the various government agencies as well as in the target academic institutions. It is, therefore, suggested that the availability of the enhanced funds be made conditional to the desired reforms being put in place at all levels.

A summary of the financial outlay to implement the suggestions is provided in Annexure 1.

1.0 UPGRADATION OF UNIVERSITIES, COLLEGES AND NEW INITIATIVES IN SCIENCE AND TECHNOLOGY

1.1 Special Assistance should be provided to ten selected Universities to establish world-class Premier Universities in the country

At least ten Universities in the country need to be brought at par with the best Universities in the East Asian region if not with the best at the global level. The identified Universities must provide education at the undergraduate and postgraduate levels and conduct research of high standard. A financial assistance of Rs. 200 crore for each identified University will be required for upgrading infrastructure, laboratories, instrumentation and for repairs in their Science departments. These Universities should have uninterrupted water and electric supply, waste disposal systems and proper computational, internet and library facilities.

These Universities will require a substantial increase in their recurring expenditure so as to maintain the laboratories, instrumentation, computational facilities and databases. These Universities will also require some seed money for research. The recurring expenditure on bandwidth, journals and laboratories will have to be increased 3-4 times over current values. Each Science department within these Universities will require a grant of Rs. 10 lakhs per annum for proper laboratory training of students.

This proposal is in keeping with the philosophy that led to establishment of two new IISERs in the country and attempts to achieve the same goal by taking advantage of the already existing infrastructure in select universities and making investments only incremental to those already made by the country.

1.2 Every state of India should have a University at par with the best Central Universities with respect to funding and academic standards

Special assistance may be provided to at least one University in each State to upgrade infrastructural facilities, libraries and instrumentation to bring these Universities at par with the best Universities/Institutes in India. A grant of Rs. 50 crore may be provided to each such university with the stipulation that most of the expenditure should be on teaching, learning and research related activities rather than on construction of new buildings. These Universities must also strengthen their undergraduate education. These identified universities may be upgraded to Central Universities, if necessary.

1.3 Leading postgraduate teaching Universities and IITs should be encouraged to impart undergraduate science education

In India, the IITs and some leading Universities have excellent departments offering M.Sc. programs in science subjects and also have a good ambience for research. Most universities in the world have both PG and UG programs on the same Campus in an environment of research. Ten high quality post-graduate teaching institutions in the country may be identified and supported adequately to start undergraduate B.Sc. programs. Each may be provided with Rs. 20 crore for implementation. Block grants may be given to further upgrade the research facilities at these selected places. This measure will help us in attracting bright students to pure science courses.

1.4 At least 200 undergraduate Colleges in science, technology and social sciences be provided additional assistance to develop into Colleges of Excellence

Neglect of undergraduate (non-professional as well as professional) education will cost the country very dearly. It is suggested that undergraduate education in all streams – science, social sciences, languages, commerce and technology be provided major support during the XI Plan.

A scheme was earlier started by the UGC to recognize Colleges of Excellence and to provide them additional grants of Rs. 30-50 lakh. This amount is too meager to bring about any significant change in quality. A one-time grant of Rs. 2 crore and a three to four-fold increase in recurring grants (other than expenditure on salaries and administration) will be required to improve the infrastructure, inter- and intra-net facilities and libraries in undergraduate Colleges. Around twenty Technology Colleges should be upgraded. Upgradation of Technology Colleges will require higher levels of resource input, around Rs. 5 crore per college.

1.5 Encourage interdisciplinary movement between Science & Technology streams and industrial R&D by establishing 20 Engineering Schools that admit students with a Bachelor's degree in Sciences for a two-year B.Tech. degree in selected areas requiring strong science-technology interface

This is a new proposal and has received very wide support. Urgent steps need to be undertaken to enhance the perceived status of conventional B.Sc. degrees in Universities as a career option. Currently, the low morale of B.Sc. students in the country is a very worrying feature of the higher education scenario in the country. A large number of college students pursuing B.Sc. degrees, several of them talented and motivated, feel 'left out' and 'discarded' by the system. Most of them pursue their degrees without any enthusiasm or motivation and are constantly looking for opportunities to defect to the 'professional' streams.

An important measure to address the problem of low morale in B.Sc. degrees is to initiate post-B.Sc. 2-year B.Tech. programs, followed by 2-year M.Tech. programs. This will provide greater choices in career development to the meritorious amongst the 16 lakh students with undergraduate degrees in Science.

These schools would offer B. Tech. degrees in frontier areas of industrial R&D like robotics, design, microelectronics, materials and nanomaterials, chemistry and chemical engineering, software engineering, nuclear sciences and nuclear technology, biomedical sciences and biotechnology. An expenditure of Rs. 50- 150 crore would be required for the development of infrastructure for each such college. Recurring expenditure will also have to be provided at par with those in good colleges of engineering.

When implemented, this proposal will permit:

- Freedom of movement for meritorious students between Science and Technology.
- Students to choose between technology, basic sciences and teaching streams at the age of 20, when they can make more informed decisions.
- Development of human resource that is comfortable with both science and technology and, therefore, is more tuned to converting knowledge into innovation for wealth generation.
- Creation of human resource for industrial R&D in many key areas.
- Young students to be freed from the excessive pressure of studies in class XII and also offer them relief from choosing subjects under parental pressure.

- Increased choice after a bachelor's degree so that bright students will choose to study sciences and basic sciences in larger numbers thereby adding to the prospects of quality research in the basic sciences.

1.6 The three Inter-University Centres for Science Education and Research need to be developed further

The establishment of the three Inter-University facilities (IUCAA at Pune, NAC at New Delhi and the UGC-DAE Consortium for Scientific Research at Indore) is one of the successful UGC initiatives in the past decade or two to upgrade science education and research in Universities by making available major facilities centrally. These Centres are noted for their good work and academic ambience and have offered excellent opportunities to several thousands of University/College teachers and research students for carrying out internationally competitive research. A substantial block grant to each of these Centres will strengthen their programs further, resulting in direct benefit to many active and motivated teachers and research students. Other such centres, especially in the area of Life Sciences, should be established in consultation with the scientific community.

1.7 The Competitive Grant System for Research and Development should be further strengthened

All over the developed world, Science and Technology research in Universities has been supported through a competitive grant system. Fortunately, India also has an extensive competitive grant system. However, this grant system needs to be substantially strengthened through significantly increased financial outlay and major administrative reforms.

- Projects in University-Institution-Industry mode should be provided major support. The NMITLI scheme of CSIR, and Technology incubators of DST are some existing examples. Funding for such initiatives should be increased threefold.
- All proposals under the competitive grant system should be on a Proposal Tracking System where the progress of the proposal can

be monitored in an open manner. Decision on the proposal and release of funding should not take more than six months.

- Each project given to an investigator in a University should have provision for overheads amounting to 30% of the total grant.
- The FIST (DST), SAP (UGC) and COE (DBT) grants, which are given to departments to improve their research competitiveness need further strengthening. For example the FIST grants do not effectively take care of recurring expenditure on the facilities that are created. All these programs should include recurring grants to maintain and run the equipment and other facilities that are created. Funding for all these grants needs to be enhanced several-fold in the XI Plan.

Although the suggestions in our proposal are for science and technology education, it is important to note that an integrated development of the country is possible only when education and research in other areas is also strengthened. Therefore, it is essential that social sciences, arts and other areas be also provided adequate research funds through competitive grant systems. Research in most of these areas is generally lagging far behind international standards.

1.8 Development of e-learning materials should be given very high priority

Worldwide e-learning resources are being developed for upgrading skills of those who are employed and also for sustaining life-long learning. In India e-learning can achieve much more. E-learning can improve access to education and establish some basic minimum level of standards in pedagogy across the country. Further, an open platform will allow constant improvement of the course material. E-learning could be made challenging for the bright and helpful for the mediocre students. E-learning platforms could also help college teachers across the country catch up with the latest developments in their fields.

Development of e-learning materials in the core and vocational subjects and in language learning should be a major priority of the XI Plan. As the tradition of writing quality course materials and text books is not very strong in India, a major national effort will have to be mobilized to prepare world class e-learning materials. Inputs from the software industry will also be required. The Science Academies can take the major initiative in these tasks in view of the strengths of their Fellowships.

The INFLIBNET initiative by the UGC, which is expected to enable universities, colleges and other academic institutions to keep abreast of the current knowledge, needs to be actively strengthened, by additional financial resources to the programme itself, its professional management, and by improving vastly the electronic connectivity of the university and college networks. We do not put down any suggested outlays for this since we believe that world-class electronic connectivity of educational/ research institutions will be an area of major investment in the XI Plan under other provisions.

1.9 Fee increase and resource mobilization should not lead to cuts in grant-in-aid

A more fair and robust system of education will require significant increase in tuition and other fees. In order to facilitate higher education for the meritorious students from financially weaker backgrounds, adequate provisions for fellowships/soft loans will also need to be made.

Currently income from any increase in fees by Universities is deducted from their grants-in-aid. This is totally undesirable. Any resources generated by a University should be invested in the institution itself instead of being deducted from its grants-in-aid. In fact, to encourage resource generation by Universities, the MHRD and UGC should provide matching grants so that the Universities move on to achieve financial robustness.

2.0 HUMAN RESOURCE DEVELOPMENT

Excellence in education will require improvement in infrastructure, well-crafted courses, e-learning materials, access to laboratories, computational facilities and above all well-trained and highly motivated teachers. We believe that active research is integral to faculty members' work and enhances what the student learns. We propose the following measures for improvement in human resources.

2.1 The scheme of summer schools for meritorious undergraduate and postgraduate students should be expanded to cover more students

The Indian Academy of Sciences, Bangalore is implementing, for more than a decade, a very forward-looking program to provide scholarships to undergraduate and post-graduate students for summer training in some of the leading laboratories in the country. This scheme should be increased several fold. The summer training should be imparted in two ways: the first approach is the current method of providing exposure to bright students in good laboratories while the second approach would be to provide funding to the best Institutions and University departments in the country to organize 2-4 week intensive courses in laboratory work, backed by appropriate sets of lectures for students. This will provide opportunities to bright students to learn new laboratory techniques and also expose them to scientists active in R&D. Besides the selected university departments, the national laboratories (CSIR, DAE, DRDO, ICMR, DBT etc.) should be encouraged to participate in such workshops for students. The Science Academies may be entrusted the responsibilities of organizing these activities.

2.2 National Merit Scholarships for B.Sc. and M.Sc. students

1000 under-graduate and 500 post-graduate science students should be selected nationally every year for award of National Merit Scholarship of Rs.1,000/month and Rs. 2000/month respectively. This will help attract good students to study basic science with self-esteem and confidence. It may be noted that most of those who are selected for the various Science-talent search scholarships pursue professional rather than basic science courses. Therefore, scholarships exclusively for basic science students are necessary.

2.3 Research fellowships for Ph.D. students need to be enhanced

In order to attract more students to join Ph.D. programs at various universities and colleges, the numbers and quantum of JRF and SRF needs major revision, especially in view of the fact that other professions provide much more lucrative salaries and perks. It is suggested that JRF should be increased to Rs.12,000.00/month and SRF to Rs. 15,000.00/

month. The NET (CSIR/UGC) and equivalent tests need to be re-vamped to ensure quality of those selected for JRF/SRF and thus for Ph.D.

2.4 Meritorious doctoral students should be recognized through teaching assistantships with stipends over and above the research fellowships

Identifying talented, meritorious students and encouraging them through recognition is very important to attract students into research and teaching. It will be very useful to provide teaching assistantships to the deserving students joining Ph.D. programs in the Universities. These assistantships will carry a stipend over and above the CSIR/UGC or other research Fellowships. These students will assist faculty members in laboratory work and/or in tutorials for a certain specified number of hours. This will improve laboratory practicals and keep meritorious students in touch with teaching during their Ph.D. research programs.

2.5 Young school students should be given stipends to spend time in active laboratories and institutions

A new programme involving about 1000 secondary school children (classes 6-8) every year from not-so-elite schools from villages, small towns and cities across the country needs to be started which would enable them to spend two weeks in various institutions of DAE, DST, DBT, CSIR, ICAR, ICMR, Space, Defense, Public and Private sector R&D companies and selected Universities. These children may be selected on the basis of recommendations of their teachers or from among the responses received following national advertisements through the media. Each child may be given a fellowship of say Rs. 3,000 for travel and stay, and during the 2 weeks, he/she will observe and even carry out hands-on work at these places. To catch them young in Science, Technology, Agriculture, Medicine (STAM) is vital for attracting talent for a career in Science. This affirmative action model is somewhat like the Kishore Vaigyanik scheme, but at a level lower, and can be organized along similar lines.

2.6 Post-doctoral research culture must be promoted for improvements in R&D

Unlike the advanced countries, where a large pool of post-doctoral research fellows carries out the bulk of high-quality research, there is a near total absence of a post-doctoral culture in India. One way of encouraging the growth of such an environment in India would be to give positive recognition to good post-doctoral research work in India at the time of appointing faculty/scientists. Further, the stipends must be improved from the current less than Rs. 15,000 per month to Rs. 25,000 per month. There should be provision of hostels/housing for post-doctoral fellows.

2.7 Refresher courses need to be strengthened for improvement in quality of existing faculty

Besides expanding and revamping the UGC's Academic Staff Colleges, more pro-active "hands-on" training in laboratory methods in different emerging areas needs to be provided to the faculty across the country. Every year, there must be at least 200 training courses, of 2-3 weeks' duration, at established centres (research institutes and university departments). Each course should have an intake of at least 15 teachers. Special attention may be given to teachers from colleges from less developed areas of the country, so that the training can have a ripple effect in the neglected parts of the country. Besides the UGC, DST and DBT, the Science Academies should play a major role in these training programs on the basis of the strengths of their Fellowship (the Indian Academy of Sciences, Banagalore, is already organizing such workshops). It would strengthen the participation of teachers in such quality training workshops if they are also recognized as being equivalent to the Refresher Courses conducted by the UGC Academic Staff Colleges.

2.8 Meritorious scientists should be recognized by creating positions of National Professors

A new cadre of National Professors should be created to recognize eminent scholars/researchers. The National Professors should be selected at the national level by a panel of the best Indian scientists. The two Academies can play a major role in the selection process. During the XI plan period at least 200 scientists/researchers should be recognized as National Professors. They should be provided a fixed salary of Rs. 25,000.00 + allowances per month (salary equivalent to that of a Vice-Chancellor of a University) and appropriate research grant.

2.9 Working conditions for women in Science and Technology need to be Improved

Although the number of women at post-graduate and doctoral levels in various universities is high, very few of them make sufficient advance in their careers for a variety of social reasons. In order to attract and retain meritorious women in active teaching and research in science and technology, the following measures are suggested:

- All major institutions of higher learning and research should have on campus crèches.
- Funds need to be allocated to pay for the salary for replacement of woman faculty that needs to take a break (1 or 2 years, at the most) for child bearing and rearing.

2.10 Incentives should be provided to teachers and researchers to make these professions more attractive for the younger generation

The following measures are suggested:

- It is obvious that the quality of the young degree-holders generated by the various colleges and universities depends heavily upon the quality of teachers. In the current market-driven globalized economy, the pay-packets and working conditions have to be competitive to attract talented persons to teaching and/or a research career. The basic salaries need to be at least doubled at all levels. To make the university jobs truly attractive, it is crucial that other conditions, like housing and better facilities/environment at the place of work leading to better quality of life, are also provided.
- Provision for advance increments to bright young appointees must be effectively implemented to attract and retain deserving candidates. Young bright Ph.D.s should be given faculty positions with adequate "start-up" grants soon after their obtaining the Ph.D.

degree to enable them to start productive teaching/research career at an early and more creative age.

- All new faculty members should be provided a ‘start up’ grant of at least Rs. 10 lakh for faculty in experimental sciences and Rs. 2 lakh in theoretical sciences.
- All initial appointments should be on a five-years contract with adequate start up facilities; renewal and permanent placement has to be done only after a rigorous and objective evaluation of the performance during the five-year period.
- During the first two years, the teaching hours of first-time appointees at the Lecturer level should not be more than 75% of the stipulated load to enable them to get used to the teaching system and to also have sufficient time to set-up their research activities.
- Wherever necessary, University campus housing should be significantly enhanced. To begin with, each of the major Universities may be provided Rs. 5 crore on this account.
- Currently, college and university teachers have only two promotions. A third promotion for the meritorious through selection will make teaching more attractive as a career.
- A voluntary retirement scheme (VRS) may be introduced to make room for much needed “fresh and young blood”.
- To encourage university/college teachers to undertake externally funded research projects, particularly those sponsored by industry, a certain amount (a part of the recurring grant, not exceeding 50% of the gross salary of the PI) may be added to their pay for the duration of the project approved to them.
- Every Faculty member should be provided financial support to participate in one international conference at least once in two years. Adequate provisions for study/sabbatical leave must also be ensured.

3.0 ACCOUNTABILITY AND ADMINISTRATIVE REFORMS

The provision of additional funds to Universities and Colleges in all cases should be linked to enhanced accountability and administrative reforms. The following reforms are critical:

3.1 Vice-Chancellors should have a term of 5-years so that positive changes can be initiated and pursued. Only those with strong academic and administrative values should be appointed as Vice-Chancellors, without any political interference.

3.2 To ensure uniformity and quality, Universities provided with enhanced funding should be made Central Universities and should have the President of India as Visitor. These Universities should admit students from all over the country.

3.3 All research institutions and university departments must have an audit of their productivity in terms of new and original research findings published as research papers in quality journals and/or patents/industrial processes developed in relation to the total expenses incurred.

3.4 All promotions must be clearly linked to performance; the philosophy and practice of merely "time-bound" promotions should be scrapped.

3.5 All Universities/research institutions should avoid in-breeding by generally not hiring their own students immediately after Ph.D.

3.6 Close monitoring of Universities in terms of affirmative action and fulfilling of social obligations should be done regularly.

Publicly funded academic institutions in India are governed by a wide variety of rules and regulations and consequently follow very different practices. There is need for urgent action to bring in uniformity of rules and regulations, by incorporating the best of these varying practices. The rules should be appropriate for the purpose of the academic institutions and should provide autonomy, public accountability and transparency at all levels. Support should be contingent on the necessary changes being implemented.

ANNEXURE I

S. N.	Recommendation	Rs. in Crores	Total (in Crores)
1.1	Special Assistance to ten Premier Universities a) One-time grant b) Recurring grant (average 10 Science departments per university) for five years i) Research@Rs. 10 lakhs p.a) ii) Teaching @Rs 10 lakhs p.a.)	2,000.00 50.00 50.00	2,100.00
1.2	Up-grading of State Universities a) One-time grant b) Recurring grant (average 10 Science departments per university) @ Rs. 5 lakhs p.a. per department	1,450.00 75.00	1,525.00
1.3	Undergraduate science education in leading Universities and IITs	200.00	200.00
1.4	Enhanced assistance for 200 undergraduate colleges a) One-time grant for 160 pure science and 40 engineering colleges b) Recurring grant for laboratories @ Rs 20 lakhs p.a. per college) for five years	420.00 400.00	820.00
1.5	Establishment of 20 Engineering schools for two year B.Tech. degrees a) One-time grant b) Recurring grant (only on labs, maintenance etc.)	1,500.00 200.00	1,700.00
1.6	Assistance for Inter-University Centres	150.00	150.00
1.7	Assistance for Competitive Grant Systems	To be worked out by individual Science and Technology Departments	
1.8	Development of e-learning materials	50.00	50.00
2.1	Summer schools for undergraduate and postgraduate students	30.00	30.00

2.2	National Merit Scholarships for B.Sc. and M.Sc. students	12.00	12.00
2.3	Enhanced research fellowships for Ph.D. students	150.00	150.00
2.4	Teaching Assistantship for doctoral students	150.00	150.00
2.5	Stipends for school students	2.00	2.00
2.6	Enhanced post-doctoral fellowships (500 PDF per year @ Rs 25,000pm)	75.00	75.00
2.7	Refresher courses for faculty improvement	50.00	50.00
2.8	National Professors	20.00	20.00
2.9	Improvement in working conditions for women a. Crèche facilities (at 100 universities @ Rs 20 lakhs per crèche) b. Salary for replacement appointment	 20.00 30.00	 50.00
2.10	Incentives for teachers and researchers	250.00	250.00
	Total		7,334.00

Note: The above does not include the outlay on several of the items suggested. These include the enhanced salaries of teachers/scientists, assistance provided by UGC/DST/DBT in the form of SAP/FIST/COE programs, the research grants provided by different agencies etc. The outlay on these should be projected by the concerned departments/ agencies.

Appendix II

XI Plan, higher education and recommendations of the science academies

S. C. Lakhotia and Deepak Pental

Since 1951, the Government of India has been formulating five-year plans for the development of the country. The task of formulating successive five-year plans is steered by the Planning Commission. We are now at the threshold of the XI Plan and the past few months have seen a flurry of activity related to budgetary allocations for various sectors. Allocations for education, and research and development (R&D) are certainly a major concern at this juncture.

To guide national policy and to rationalize resource allocation for higher education and for science and technology, the Indian National Science Academy, New Delhi and the Indian Academy of Sciences, Bangalore jointly prepared a document, 'Higher Education in Science and Research & Development: The Challenges and the Road Ahead', which contains extensive proposals for revamping and restructuring of higher education. The document has been prepared after extensive discussions and incorporates inputs from the members of the two Academies and a large number of educationists and researchers. The document also took into consideration some comprehensive reports like the India Science Report (2005) and Report of the Task Force for Basic Scientific Research in Universities (2005). The document was submitted jointly by R. A. Mashelkar and T. V. Ramakrishnan, Presidents of the two academies, to the Planning Commission on 8 August 2006. The full text of the document is available at the sites http://www.insa.ac.in and http://www.ias.ac.in.

Unlike the situation in many countries, where the advice of the academies is either sought by the Governments or the academies on their own tender advice on vital national issues, academies in India have generally stayed mute spectators in the process of the formulation of national policies. The initiative taken by the two academies is, therefore, a welcome development and hopefully will set the trend for their active participation in developing policy frameworks for education and R&D. Wider availability of the document will hopefully bring forth new and innovative ideas for future discourses and implementation.

The document proposes a total outlay of Rs 7334 crores for enhancing competitiveness of select college and university education and to promote a culture of R&D in the universities. Given the size and population of the country and the enormously large number of Institutions of higher learning (universities, deemed universities and colleges), it is obvious that even with the proposed budget, developmental activity will have to be selective; otherwise the resources will get thinly spread and the critical level essential for a quantum jump in standards will not be available. The proposal from the academies, therefore, suggests identifying ten universities and funding these substantially 'to establish worldclass premier universities in the country'. The proposal, however, goes further and recommends reasonably increased allocations for all universities. It further suggests that every state of India should have an university at par with the best of the Central Universities with respect to funding and academic standards.

The proposal recommends integrated B Sc and M Sc degrees to attract meritorious students to science courses and suggests involvement in undergraduate education of those universities which currently only cater to postgraduate education. In addition, it is proposed that 'at least 200 undergraduate colleges in science, technology and social sciences be provided additional assistance to develop into Colleges of Excellence'. An important and timely suggestion in the document is aimed at providing wider options to B Sc students and to develop new avenues of industrial R&D so as to 'encourage interdisciplinary movement between science and technology streams, and industrial R&D by establishing 20 engineering schools that admit students with a Bachelor's degree in sciences for a two-year B Tech degree in selected areas requiring a strong science–technology interface'.

Several suggestions have been made in the document to attract young students to the basic sciences. These include merit scholarships,

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summer schools for undergraduate and postgraduate students, exposure of school students to research activities, teaching assistantships for meritorious doctoral students in addition to research fellowships and promotion of postdoctoral work through enhanced fellowships, housing facilities and due recognition for research conducted in India.

For attracting bright young people to careers in teaching and R&D at the universities and colleges, a slew of recommendations have been made which include upward revision of salaries, attractive 'start-up' grants, 'advance-increments' to deserving candidates, appropriate facilities for women researchers, contractual positions with an initial appointment for five years, provision of a third promotion in colleges for meritorious teachers, support for attending international conferences and payment of honoraria in projects sponsored by the industry. The document recommends introduction of VRS for those who no longer enjoy teaching and creation of a cadre of 'National Professors' to recognize the meritorious.

The document calls for strengthening of the Competitive Grant System being run by the Department of Science and Technology, the Department of Biotechnology, CSIR and other departments of the Government. To make research more viable at the universities, it recommends that overheads should be pitched at 30% of the total grant. All proposals should be placed on a Proposal Tracking System and the time from submission to the release of funds should not be allowed to exceed six months.

The document also calls for a set of 'accountability norms and administrative reforms' to make the best use of enhanced funding possibilities. The proposed reforms include a term of five years for Vice-Chancellors of state universities, upgradation of one state University in every state to a Central University with the President of the country as the Visitor to these upgraded universities, regular evaluation and grading of teaching, curricula and research, putting an end to inbreeding (hiring own students immediately after their Ph D) and close monitoring of affirmative action.

While launching the Knowledge Commission in 2005, Prime Minister Manmohan Singh spelt out succinctly the challenges and directions for our future as a knowledge economy – 'At the bottom of the knowledge pyramid, the challenge is one of improving access to primary education. At the top of the knowledge pyramid, there is need to make our institutions of higher education and research world class… The time has come for India to embark on a second wave of nation building… Denied the investment, the youth will become a social and economic liability'. These are wise and sagacious words. Since the launching of the Knowledge Commission many new developments have taken place, which include extension of reservations to OBCs and an increase of 54% in the number of seats at the Central universities. To carry out expansion, inclusion and maintaining excellence at the same time will be a demanding and challenging task indeed.

The recommendations from the two academies will hopefully be considered carefully by the Planning Commission and the Government for achieving the avowed goals of expansion, inclusion and excellence in higher education. Decisions taken now for the XI Plan will have enormous repercussion on human resource development, innovation and economic growth of the country.

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Appendix III

A representative model of courses in the 4-year B.S. programme is outlined below.

I year	
I semester	**II semester**
Maths-I + computer lab	Maths II
Physics I + lab	Physics II + lab
Chemistry I +	Chemistry II + lab
Biology I + lab	Biology II + lab
Communication skills	Electronics/History of Science
II year	
I semester	**II semester**
Maths III	Maths IV
Physics III + lab	Physics IV + lab
Chemistry III + lab	Chemistry IV + lab
Biology III + lab	Biology IV + lab
Earth and Environment	Humanities course
III year	
I semester	**II semester**
Major – 3 courses with lab as applicable	Major – 3 courses with lab as applicable
Electives – 2	Electives – 2
IV year	
I semester	**II semester**
Major – 3 courses with lab as applicable	Major – 2
Electives – 2	Research project

Course in one subject could be an elective in another subject.

It may be noted that a given institution should develop the specific combination of courses (with varying emphasis on individual components), keeping in view their own expertise. For example, those interested in majoring in the field of Earth Sciences, may have more courses in these fields during the third and fourth semesters.

Load distribution

- A student would take 5 full courses each semester (with not more than 27–30 class-room contact hours per week), including laboratory where applicable
- In the first two years, a course would be typically 2 lectures, 1 tutorial + lab of 3 hours duration. Subsequently, each theory course will have 3 lectures and each lab will be 3 hours duration.
- Students are expected to attend colloquia in the first 2 years, and seminars in their major subjects in the subsequent semesters.

Appendix IV

About the 4-year B.S. programme concept – Some further suggestions

1. Scope of proposals

The basic proposal is to suggest ways to improve the UG and PG teaching of Science in the country. As part of these proposals, the 4-year programme is only one of the proposals. The other and equally important proposals relate to providing more holistic and integrative curricula for the existing B.Sc. and M.Sc. programmes.

2. Introduction of the 4-year B.S. programme

In the first place, this is suggested to be introduced initially at only those institutions which have good ongoing research, PG and UG teaching programmes so that they can develop a good academic programme without major hurdles. Only if the system works well and if the remaining academic institutions improve their infrastructure etc (which we hope would indeed happen), the entire country may follow this pattern over the course of the next 10 years.

3. 4-year B.S. as a step towards Ph.D.

This is open to any student who can compete for admission at the institutes that offer such a course. It is expected that the provision of continuing for Ph.D. without the need for a separate M.Sc. would make it more attractive for many students to compete. After B.S., it would be a dual-degree programme so that on successful completion, the candidate gets M.Sc. as well as Ph.D. degree

4. Equivalence with conventional M.Sc. for employment

To address this issue, it is suggested that the Ph.D. would involve course work in addition to research. Some places may decide to provide M.Sc.

degree only through one year research, if they so wish. However, some course work is also desired. Those who complete the course work (and/or the required research project), may exit after one year with an M.Sc. degree, while those who successfully complete the full requirements, get M.Sc. as well as Ph.D. degrees

5. Continuation of different modes of B.S., B.Sc., M.Sc., Ph.D. etc

The multiple modes running parallel would definitely bring in some additional difficulties. However, any changeover period increases "entropy" and thus needs greater energy to put things in place. Nevertheless, it may be noted that even now we do have multiple modes in the various universities, autonomous colleges, "deemed to be universities", private universities, IITs, NIT's, IISc, IISERs and the other engineering/technology colleges. Thus the addition of one more variable in the form of 4-year B.S. may not be an unsurmountable situation, compared to its distinct academic advantages.

6. Extra year compared to present B.Sc.

Those who get through the 4-year programme and continue for Ph.D., would save one year of M.Sc. and thus will find it more attractive. As noted above, they can also exit with M.Sc. degree.
At the same time, it is also believed that those who complete an academically well structured, 4-year B.S. would be better equipped with knowledge and application and thus would stand better chances for employment, even if they do not wish to continue for Ph.D.

7. Inclusion of Biology and Mathematics in common curriculum

The present, nearly universal practice, of bifurcating students at school level and further placing them in separate compartments at B.Sc. level is certainly not the best that we should offer to our younger generation. It is not a question of forcing the students, it is a question of perception on part of the seniors to work out the most appropriate path for our younger generation. The IISERs have introduced a more holistic curriculum than the present 3-year B.Sc. and apparently the students (and their parents) are not protesting. A holistic and integrative curriculum obviously requires greater efforts on part of the students as well as teachers. This extra effort is essential if we really want our younger generation to be a recognizable knowledge force, rather than let them take simpler paths and thus remain incapable of realizing their own potential.

8. Status of Academies' proposals

The proposals in the Position Paper are only suggestions. They are to be presented to the various regulatory authorities that govern the academic institutions and it is for them to decide what to do.