The present dismal state of higher education in the country is a matter of serious concern, since this has severely limited the potential of its enormous and otherwise capable youth power. With a view to rectify and improve this state of degeneration, the three Science Academies of the country – Indian Academy of Sciences (Bangalore), Indian National Science Academy (New Delhi) and National Academy of Sciences India (Allahabad) – have been jointly coordinating and supporting several programmes relating to science education since April 2007. These are under the overall supervision of the combined Science Education Panel, which has members from all the Academies.

The joint Education Panel has also taken up general issues relating to science education at the undergraduate, post-graduate and doctoral levels in our colleges and universities. It held discussions with groups of teachers at the meetings of the Indian Academy of Sciences in July 2007, November 2007 and July 2008, on ways to improve the existing structures of curricula at various levels as well as to think of possible new initiatives. As a follow up, the three Academies jointly sponsored a one-day meeting at Bangalore on 24 May 2008, to discuss the possibility of introducing a 4-year Bachelor of Science Programme. Several heads of institutions, concerned individuals and many Fellows of the Academies participated in this meeting.

Based on these various inputs, a Position Paper was initially drafted. This draft was discussed by the Councils of the three Academies, and based on the feedbacks, a final document entitled ‘Restructuring post-school science teaching programmes’ has been jointly released. This document has been presented with the ‘hope that the suggestions will be seriously considered by the concerned agencies for their effective implementation’.

The main text of this document is reproduced here so that readers of Current Science can further discuss the issues and the suggestions at a much wider level and thus help fulfill the aspirations of the country’s increasing youth power. The Appendices mentioned in the text can be seen at the websites of the three Academies: http://www.iassc.in; http://www.insa.ac.in; http://www.nasi.nic.in

– S. C. Lakhotia and N. Mukunda

Restructuring post-school science teaching programmes

Joint Science Education Panel (IASC, INSA, NASI)

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. A detailed proposal for reform of higher education in science is presented.

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, and 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 (see Appendices I and II). It is clear, however, that mere increase in investment cannot improve the quality. Therefore, the Science Academies 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.

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 predefined 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 the 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 ‘mathematics’ or ‘physics’ (or ‘non-medical’ or ‘pure science’) group, and 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 no biology, while those opting for the ‘biology’ stream cannot study physics, mathematics, statistics or computer science.

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 an 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 practice science’.

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 postgraduate 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 a 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 the 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, computer science, etc. are being introduced as substitutes for 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 the 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/BE) offered by IITs, NITs and the state and privately run colleges.

(2) A four and a half-year (+1 year internship) medical degree (MBBS) offered by the central, state and private medical colleges.

(3) A five-year Master of Science (M Sc or MS) 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 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, fail 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 limited facilities and capabilities. Obviously, most of these institutions do not offer a meaningful engineering 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;
SCIENCE ACADEMIES’ POSITION PAPER

- 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 the B Sc curricula, which makes the students disinterested;
- Typically ten or more years are required after school to get a Ph D degree. 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 switch-over from science to technology/engineering and vice versa is generally not possible due to the unequal duration 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 the 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.

Country needs flexible and multi-choice higher education system in sciences

In view of the great diversity of the 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 the 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 undergraduate and postgraduate teaching programmes has failed to prepare the youth with qualifications required even in current times. This failure would only magnify in the 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 have 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 undergraduates 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 a 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 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/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 a large number 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 its 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.

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.

Proposal for introduction of a 4-year post-school Bachelor of Science 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 4-year Bachelor of Science (BS) programme following which, the successful graduates can directly join Ph D programmes. Some of the obvious advantages of the 4-year BS programme, 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 four years than after $3 + 2$ years under the present system.

- The 4-year BS 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 BS programme would facilitate the possible switch-over 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 BS programme may be a high-quality preparatory first part of a research programme leading to a Ph D. Over a longer term (say 10–15 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.
Flexible and multi-choice UG and PG science education programmes

While it is widely agreed that a 4-year BS 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 BS 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, IITs and IIISERs) for the +2 qualified students followed by Ph D.

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

The 4-year BS 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 programmes, 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 BS/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 BS programme would be a credit-based semester system in all engineering/science colleges/institutions.
4. BS students will opt for a major subject in the last two years.
5. There should be transfer of credits within and between institutions.
6. Students in the final year of BS 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 and laboratory practices.

Subsequently, the BS students would acquire substantial knowledge/skill in one subject (major) and get additional training in at least one more subject (minor). 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 multidisciplinary training.

Additionally, it is 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 the 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 eight semesters of this programme is given in Appendix III. Appendix IV provides further suggestions/explanations about the proposed 4-year BS programme.

Ph D programme following the 4-year BS programme

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. BS 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 3-year B Sc and 2-year M Sc courses

In view of the diversity of the 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 inte-
grated learning, rather than making the students specialize 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. The first year of the 3-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/mathematics’ 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 programming, 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 the introduction of specialized courses like biotechnology, bioinformatics, genetics, etc. at the undergraduate level as well. However, in the absence of integrative learning of the basics of biological systems and adequate laboratory work, such courses, in general, produce a large number 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 30–40% 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 the 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 students’ 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, students should be encouraged to take some extra credits through courses in the 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 directly for the M Sc degree. Such integrated courses have the advantage of maintaining continuity from one level to another, thus avoiding 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 active in research, so that the students are exposed to quality laboratory exercises and research environment from the first year onwards.

3. As suggested for the regular B Sc (and M Sc) courses, the integrated programmes must follow the semester
system with wide-based curricula and sufficient flexibility in selection of courses by individual students, keeping in view their 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 three 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 two 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 publish 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, 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 BS, depending upon the nature and level of training, and should provide a diploma certificate.

Summary recommendations

In summary, as shown 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 BS
2. 3-year B.Sc
3. 5-year Integrated M.Sc
4. Admission to Ph.D after four-years of BS 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 three-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.

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 BS programme must be introduced initially at only those institutions which have good ongo-
ing 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 BS 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 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 BS programme may be introduced at all institutions over the next 10 years.

The 4-year programme will be at variance with the present minimal requirement of M Sc qualification (five years post-12 school level) for most government 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 the 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.

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, “Jnana vijnana-sahitam”. It should not only train the intellect but bring grace into the heart of man’.

Aurobindo highlighted three basic principles of the teaching–learning process:

1. Nothing can be taught – the teacher is not an instructor or taskmaster, 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.

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, and (6) limited options for movement between science and technology streams.

Keeping these in view, it is suggested that a new 4-year Bachelor of Science (BS) programme should be introduced, at select institutions to begin with, which the +2 pass students can join. Subsequently, the interested and competent BS-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 BS 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 BS 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 BS 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 BS 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.