

We publish below a report issued by the Indian Academy of Sciences reflecting its concern on the state of university education in the country. It suggests ways of promoting science education with the ultimate goal of attaining excellence in science. Readers are welcome to express their views on this paper.

—Editor

University education in science

1. Introduction

Following the expression of widespread concern on the state of university education in science in the country, the Council of the Indian Academy of Sciences decided that an Academy Paper should be prepared on the subject. Accordingly, the President appointed a Panel whose composition is shown in the Appendix. Its terms of reference were:

1. to assess the state of education in science in the country, particularly at the undergraduate level; and
2. to propose such measures as may be considered appropriate to improve the quality of education in science through the combined efforts of universities, higher institutes of learning, government authorities, voluntary agencies and the Academy.

This document is based on the report submitted by the Panel. In preparation for its work, a half-day symposium on 'University Education in Science' was organized by the Panel on 16 August 1994 at the Indian Institute of Science, Bangalore. In addition to all Fellows resident in Bangalore, the faculty and students of the Indian Institute of Science, Raman Research Institute, Indian Institute of Astrophysics, and concerned faculty from Bangalore University and selected colleges in Bangalore were invited to the symposium. Four of the panel members presented half-hour papers on the four major science streams—V. G. Bhide on physical sciences, A. Sitaram on mathematical sciences, M. K. Chandrasekaran on life sciences, and B. M. Deb on chemical sciences. There were also introductory remarks by the President, R. Narasimha, and brief invited observations by C. N. R. Rao and G. Padmanaban. Many Fellows present at the Symposium—including M. V. Bhatt, S. K. Brahmachari, R. Cowsik, V. K. Gaur, R. Narasimhan, J. Pasupathy, Phoolan Prasad, Raja Ramanna, P. N. Shankar, B. V. Sreekantan and N. Viswanadham—as well as Prof. S. Khatre of Bangalore University, contributed to the discussions.

The Panel met on 16 and 17 September 1994 for detailed discussions, as well as on 27 September 1994 to finalize its report. The Secretary of the Academy in a circular letter to all Fellows informed them of the setting up of the Panel and invited them to convey their views to it. Close to fifty responses from Fellows

were received, some containing suggestions relating to specific subjects. All of these, and the comments made during the symposium, have been taken into account in the preparation of this Paper.

The Paper is structured as follows: Section 2 recapitulates the dimensions of the problem of science education in the country, starting with a brief look at the school scene and then moving on to the undergraduate and postgraduate levels at colleges and universities. This Section also includes an account of frequently expressed perceptions of the current scene in university education in science. Section 3 reviews briefly some of the suggestions that have been made earlier by various concerned groups and agencies to tackle the problems set out in Section 2.

Section 4, in a sense the heart of this document, presents the views of the Academy on various aspects of the question of university education in science. Among the issues considered are the following: the role of Government agencies; the functioning of educational institutions; the contributions that national laboratories and R & D institutions can make to science education; patterns of curricula, flexible options for students, teacher training, needs of different groups of students; and urgently needed improvements in the teaching of particular subjects. The relationship between the social goal of equity and the academic one of recognizing and supporting excellence has also been addressed, and ways have been suggested for a reorientation of the educational system by which these goals can be seen as complementing each other.

The recommendations are given in Section 5. They have been grouped separately into those that involve major agencies and wings of Government, and those where the Academy can take initiatives on its own. Section 6 gives a brief summary of the major recommendations, for quick and easy reference.

2. Dimensions and common perceptions of the problem

Although the main focus of this document is university science education particularly at the undergraduate level, it is realized that undergraduate education is part of a continuum, starting with education at the school level and going on to research in science. It is therefore

appropriate to remind ourselves, at least briefly, of some facts concerning school, undergraduate and post-graduate science education in India, before going on to reviewing suggestions already made by various individuals, institutions and agencies. The recommendations to be given later are to be viewed against this background.

In the following, representative figures of various kinds drawn from several sources will be presented. Although great accuracy cannot be claimed for these figures, they are sufficiently reliable for drawing the general conclusions set out in this Paper.

The number of school-going students, about 12 crores¹ in 1985 has been continuously increasing at the rate of about 3% per year. However the number of well-equipped schools, in terms of laboratories, libraries and competent staff, is extremely small. Thus it has been estimated that no more than 60% of schools even have a blackboard, and less than 30% have any kind of library or laboratory facilities². To cater to these basic needs, the amount of funding provided by the Government is estimated at about 15% of the total annual school educational budget of Rs 2500 crores³. This works out to Rs 375 crores, i.e. approximately Rs 30 per student per year! The remaining budget allocation is used up for salaries and maintenance of establishments. As a result, the vast majority of schools are ill-equipped to impart a reasonable science education; yet the few that do so manage to maintain a high level of enthusiasm both among teachers and students.

Less than one percent of the students who complete the 10+2 school years go on to science education at college level. While the total number of students in all three years of undergraduate science courses has risen from about 1,28,000 in 1950 to 7,25,000 in the late eighties⁴, the percentage of the total student population choosing science after school has dropped over the same period from 32% to about 19% today. Undergraduate education is primarily imparted in a large number of affiliated colleges (about 6000 at present⁵), but generally not in university departments. The vast majority of the affiliated colleges are ill-equipped.

We may also keep in mind that, of the total university output of undergraduates each year, approximately one-third are in the sciences. One can also ask: how many really gifted and potentially creative science students are produced each year in the whole country, who go on to do research and work for a PhD in Indian institutions? A reasonable estimate, based on the collective experience of many academics in their own institutions, is that this number is not much more than 150–200. (As an illustrative example, the total number of PhDs awarded by the Indian Statistical Institute in the sixteen-year period 1979–1994 is about 120.) Typically, the same candidates get selected for admission in all the major institutions in the country for research.

Thus the number of students who are suitable and who also opt for research is appallingly small.

Against this background, we review briefly the commonly held and expressed perceptions among the members of the academic community involved in higher education and research about the present state of science education in Indian colleges and universities. There are of course fortunate exceptions, but the general view is that standards in all respects have declined rapidly and alarmingly, and unless something is done soon to remedy the situation the country is definitely heading for disaster. This is more or less uniformly the opinion expressed in the letters written by Fellows to the Panel. One quite pessimistic view is that it may already be too late to prevent disaster. On specific aspects of the whole situation, we may summarize frequently articulated views as follows.

a) There has been an alarming drop in the quality of students who opt for higher studies in the sciences after school level. The best products from schools choose to go for courses in engineering, medicine and commerce; the next most talented group opt for administrative services, bank careers and the like; those that pursue science at the undergraduate level are then largely drawn from the residue.

b) As against this, there has been no careful assessment of the country's needs for talented scientists in different spheres. The needs are obvious in sectors such as defence, space, atomic energy, health, agriculture and related fields, apart from the universities. The absence of quantitative estimates of the number of persons needed in the years to come may have contributed to the present problems. Well planned efforts to attract, train and retain appropriate numbers of scientists, to pursue a professional career in science in this country, are essential to prevent a crisis in the near future.

c) In contrast to the situation a few decades ago, students, parents and indeed society as a whole do not presently view a career in science as rewarding or challenging, or even as offering a satisfying professional life. Career opportunities in science are perceived as limited, and as being not at all comparable materially with other professions. Intimately related to these negative impressions is the fact that faculty positions in colleges and universities appear lacking in prestige and respect, and in any case what young people see all too clearly is rampant inbreeding in most educational institutions.

d) The National Science Talent Search awards scheme instituted in 1964 was definitely a very worthwhile attempt to attract the best and most highly motivated students to devote themselves to careers in science. However even here the necessary follow-up steps to retain and provide for such students have been missing. In 1977 this scheme was enlarged to the National Talent

Search award scheme, to include areas other than science. By around the mid to late eighties, only about 10% of the total number of awardees were opting for science at the undergraduate level; and the number going on to the post graduate level was even less⁴.

e) It is commonly felt that the maximum damage to our students occurs after they come out of the school system and enter the undergraduate level (occasionally even at the +2 level). It is at this stage that all curiosity, self-confidence, enthusiasm and eagerness to learn are killed. Added to this are poor methods of evaluation and debilitating memory-based examining systems. The products of Indian undergraduate programmes are definitely poorer than their counterparts in developed countries, indeed much more so than at the 10+2 level. The burden of undoing and repairing the damage suffered at the college level has then to be borne by education at the postgraduate and research levels.

f) The options available to undergraduate students entering our institutions today are limited and inflexible. The division into engineering and medical streams at the +2 level itself contributes to the problem. Practically nowhere can an undergraduate student hope to pursue emerging combinations like biology and mathematics or biology and physics. One still has to choose from old-fashioned combinations like Physics, Chemistry and Mathematics or Chemistry, Botany and Zoology. In this respect the situation has worsened even in the Indian Institutes of Technology, which were initially quite flexible and open in course and subject combinations available to students. The option of students moving from the engineering stream to science is also rarely exercised. With this absurd and self-created inflexibility, a Ramanujan would never make it today.

g) In most universities and affiliated colleges one finds low educational standards and a poor academic environment. Colleges are generally under-equipped, overcrowded and poorly staffed. Not being directly involved in the framing of syllabi or in the evaluation process, it is perhaps not surprising that most teachers become demotivated and are seen to be uninspiring. Questions from students are often discouraged, and experiments and demonstrations are few. Due to lack of experimental facilities, science is taught unimaginatively, and learnt by rote. Generally routine and unexciting topics are taught, basic concepts are poorly covered, and at the higher levels teaching remains divorced from research. Quality and excellence in teaching go unrecognized and unrewarded; the few good teachers there are, work under trying conditions. All this has a snowballing effect—the generally low standards of the output at the undergraduate level get reflected among the entrants to postgraduate education and research.

h) Too many universities and institutions have been established over the years without giving adequate

thought to the availability of teachers of acceptable quality. Without any attempts to correct the ills of existing institutions, all too often new ones are created only to face the same problems later.

i) It is widely felt that one cause for the sorry state of affairs outlined above is the government's policy of the past half century of establishing chains of specialized research institutions and national laboratories outside the university system, without proper and healthy linkages to the latter. This policy, especially the disproportionate funding of these institutions, has deprived universities of both talent and material support. Even worse, the access of young motivated students to leaders in various fields of science—natural in a university setting in developed countries and so essential to creative work at a young age—has become virtually impossible. Thus the soil where scientists of the future should grow has been deprived of some of its most important nutrients.

j) There has been hardly any initiative or involvement by private non-governmental sources of support towards higher levels of education and research. Endowed chairs, industry-supported specialized laboratories and the like are conspicuous by their absence. This is particularly unfortunate since private enterprises depend on products of the educational system for their own needs.

k) As a result of national-level discussions and suggestions for mechanisms to encourage and support scientific research, many schemes have been established by Government agencies, and these have in fact done quite well. Examples are the Science and Engineering Research Council within the Department of Science and Technology, the COSIST programme of the University Grants Commission (UGC) and the (now-abandoned) University Leadership Programme. However, in the educational sphere, though on several occasions studies and recommendations have been made to improve the situation, there has been no sustained follow-up action. Even the series of teacher-training schools held successfully in the sixties and seventies, with support from the US National Science Foundation, were discontinued due to lack of support from the Government. As a result, the enthusiasm for excellence in education has been lost.

l) With increasing political interference in higher education, the pursuit of excellence has disappeared and given place, among other things, to commercialization of education. The twin aims of social equity and academic excellence are being seen as opposed to each other. There is no intellectual debate on these overlapping problems, and it is being left to the judiciary and the political leadership to determine the directions open to society.

From this sampling of frequently heard opinions it is clear that the problems of university science education, seen in totality, are manifold, and that there has been room for continued criticism and complaint. Under these circumstances the Academy considers that there is a

need to find ways in which it can help identify and reach out to the gifted, save as many of them as possible for the pursuit of science, and make them feel that it is still worthwhile and deeply rewarding to fashion careers in science.

3. Earlier suggestions and programmes for coordinated action

In the face of the deteriorating situation described in the previous section, there have been several carefully thought-out suggestions for positive action made by responsible and concerned academic groups in the country. Therefore, before going on to a discussion of Academy's can do, both on its own and in concert with other bodies, it is useful to consider briefly some of these suggestions, at least in outline, if only to demonstrate that the desire to do something, and fairly specific proposals for action, have not been wanting.

a) *Planning Commission initiative*⁴

A Working Group to suggest ways and means of improving university science education, especially at the undergraduate level, was set up by the Planning Commission in 1989. This Group prepared a detailed proposal, expressing the hope that the action suggested would be taken starting August 1990. Though this has not happened, the proposal itself is still worth scrutiny. This proposal, or possibly some suitable variant of it, would be a good starting point to reverse the many undesirable trends in the present situation.

The proposal involves working at three tiers, each aimed at a particular segment of the student population. They may be briefly described as follows:

Tier I: This is aimed at the highly talented group of students, the number per year being estimated at about 700 (i.e. 0.5% of the total of about 1,50,000 students entering undergraduate science courses each year).^{*} The proposal is to introduce a very carefully planned five year Integrated M Sc programme in a few institutions (structured like the family of IITs). They could be independent institutes, or alternatively the UGC could choose a few Centres in existing institutions, say three Centres to cater to Physics and Chemistry, two to cater to the Life Sciences, and two to the Mathematical Sciences.

With seven such Centres, each could admit 100 students per year based on merit alone, through a common entrance test conducted nationwide. The courses in Year 1 would be common to all streams, ensuring that the foundations of each major subject are properly covered. Years 2 and 3 would be like a B Sc (Honours) programme, involving one main subject leading up to

the M Sc, and two subsidiary subjects. At the end of Year 3, a successful student could leave with a B Sc (Honours) degree, or proceed to M Sc. Years 4 and 5 should bring the student to the threshold of research.

Every student should acquire basic levels of proficiency in mathematics, computers and electronics; and the entire programme should be challenging and flexible enough to permit combinations of subjects like physics and biology, mathematics and biology etc. Students should be provided with reasonable scholarships to finance their education; and major agencies such as DAE, ISRO and CSIR should be persuaded to assure career opportunities to the most successful students coming out of this course. *Tier II:* This is aimed at the next segment of the undergraduate science student group numbering about 24,000 per year (about 16% of the students entering each year). The purpose is to raise the general level of undergraduate science teaching at a large number of selected institutions spread all over the country. The UGC may select 20 colleges each year over a five year period—thus ultimately reaching a total of 100 colleges. Financial assistance should be provided to such colleges to formulate and introduce 3 year B Sc degree courses of high academic quality and content.

Each college would admit 240 students per year, based on a locally conducted entrance test. Year 1 of the course would have a curriculum common to all students, while Years 2 and 3 would cover one main and two subsidiary subjects. By the time 100 colleges introduce such programmes, the annual admissions would reach 24,000.

Tier III: Tiers I and II together would cater to almost 25,000 students, out of the total of 1,50,000 entering undergraduate science each year. The remaining 1,25,000 (constituting 84% of the total) form such a large group that in order to improve matters for them it becomes essential to go beyond conventional systems and methods. Most of these students study in affiliated colleges, many of which have indifferent faculty and inadequate infrastructure. To cope with the vast numbers involved, one has to employ new methods of communication and distance education such as video taping of lectures by outstanding teachers, preparing entire courses of lectures on tape, periodic teacher training programmes at nearby universities, etc.

The financial estimates made in 1989 by the Working Group for a full five year programme were as follows: Tier I, 25 crores; Tier II, 60 crores; Tier III, 30 crores.

b) *UGC Curriculum Development Centres Programme*⁶

The UGC set up these Centres in 1988 in various subjects, each Centre being located at a University Department. Their terms of reference included the assessment of the quality and content of existing curricula in various universities, and evolving new curricula at

^{*}These and subsequent figures in this section are estimates made by the Planning Commission Working Group, and refer to 1989.

both undergraduate and post-graduate levels in each subject in order to promote excellence in teaching at these levels. As a result of the efforts of these Centres, detailed curricula have in fact been evolved for the B Sc (General) Course and for subject-specific B Sc and M Sc (say, in physics) courses. This careful work can provide the basis for updating and improvement by other bodies in coming years.

c) Quality University Education for Scientific Talent - the QUEST Programme⁷

This programme has been evolved by a group based at Punjab University, Chandigarh, and is similar in spirit to the Tier I Integrated M Sc programme described in subsection (a) above. The aim here is to train and produce highly competent scientists who are at the same time well-rounded human beings. The courses during the first three years would be common to all students and would cover the basics of mathematics, physics, chemistry and life sciences. Also included would be computer programming and visualization, an introduction to earth sciences, and experimental courses which emphasize planning and designing of one's own experiments. After the common three-year training, opportunities would be provided to branch out in different directions. At the end of the five-year course, each student should be highly competent in a 'principal' subject and quite well prepared in at least one other. By bringing home the unifying conceptual foundations of science, and also providing exposure to technology and problems of industry, each student should be able to act as a spokesman for science in society and have the self-confidence to attempt scientific solutions to practical real-life or field problems.

d) The M Sc (Biotechnology) Programme of the Department of Biotechnology (DBT)

The pioneering efforts of DBT in promoting post-graduate education and research have been fruitful in the life sciences area. Special M Sc courses in biotechnology in a selected group of institutions, with student scholarships provided by DBT and selection via a national level test, have, in addition to providing trained humanpower for the rapidly growing biotechnology industry, raised the general level of biology education in the country. A considerable amount of basic biochemistry and molecular biology is being imparted in these courses.

Efforts are also being made along similar lines by the Department of Electronics and the Defence R & D Organization in other subjects.

e) Efforts of the National Board of Higher Mathematics⁸

The National Board of Higher Mathematics (NBHM),

which is funded by the Department of Atomic Energy, has in the past taken many innovative steps to make it possible to spot, train and support talented students in mathematics. Apart from conducting the Indian National Mathematics Olympiad and training teams to participate in the International Mathematics Olympiad, the 'Nurture Programme' for students who have qualified in the Indian National Olympiad, and the Mathematics Training & Talent Search Programme, the Board also offers scholarships for post-graduate students tenable at various institutions in the country.

f) Initiatives of the Technology Information, Forecasting and Assessment Council

As mentioned in Section 2, no reliable estimates of the requirements of trained scientific humanpower for various national tasks seem to be currently available. The Technology Information, Forecasting & Assessment Council (TIFAC), which functions within DST, has recently taken up the task of assessing these needs in some detail. Apart from the qualitative and quantitative aspects of science education, an effort is being made to ascertain the means to provide commensurate employment and career opportunities to specially trained science graduates. TIFAC is working with agencies such as UGC, NCERT, the Department of Education, IITs, IIMs and AICTE in tackling these questions.

g) INSA Reports on the National Status in the Sciences (1994)

As part of its Diamond Jubilee activities, the Indian National Science Academy has recently commissioned special studies on the status of education in the various sciences, viz. physics, chemistry, etc. These will also be submitted as national status reports to such bodies as the International Unions of Pure & Applied Physics and Pure & Applied Chemistry. The document devoted to physics education⁵, for instance, examines the situation at the +2, undergraduate, postgraduate and predoctoral stages, and makes several valuable suggestions for improvement in the quality of education offered; it also comments on the need for and growth in popular science exposition, links with industry, efforts by voluntary bodies etc.

Apart from the above, there have been State-level efforts at assessment and improvement of university education. As an example, we may mention the report of the Committee constituted by Mr C. Subramaniam when he was the Governor of Maharashtra, to look at possible reforms in the universities in the State⁹.

Before concluding this section it must be acknowledged that the philosophical underpinnings of many of the ideas above, and those of the next section, have been

anticipated in two remarkable documents: (i) the Report of the University Education Commission¹⁰, December 1948–August 1949, and (ii) the Report of the Education Commission¹¹, 1964–1966, popularly known as the Radhakrishnan Commission and the Kothari Commission after their respective Chairmen. If (or perhaps, optimistically, we should say 'when'!) some of the suggestions in the present document are implemented, it would be most instructive to examine these early and extremely thorough reports in detail; both for the broad philosophy of their approach to the role of education in our lives, and for specific details concerning implementation of their recommendations.

4. General views of the panel

In its own discussions the Academy Panel paid careful attention to many aspects of the overall problems of science education at both undergraduate and postgraduate levels. This was against the background of the knowledge of the efforts of other groups and agencies, such as those briefly described in Section 3.

The discussions in the Panel and the large number of letters received by it from the Fellowship of the Academy brought home the point that there is a strong and unanimous feeling in the community both about the importance of science education and about the present alarmingly sorry state of affairs. The selection of commonly voiced concerns recounted in Section 2 appears to give a fair description of the present situation; urgent steps are necessary to avoid a crisis in the near future. The importance of science education of high quality, especially at the high school and undergraduate levels, cannot be over-emphasized in a country like ours. Science education becomes even more important in the context of the present efforts of the country towards globalization and a market economy. Perhaps too much emphasis is being paid to the improved prospects for attracting foreign investment that the new climate in the country provides. But the basic objective of these new policies of the Government must be presumed to be to provide an opportunity for our own trained human-power to create wealth for the nation by participating in and contributing to scientific and technological endeavours in India and across the globe. At the same time we need to support and strengthen our capacity to create, absorb and transform technology at various levels, and this can only be achieved against a background of solid foundations in the basic sciences. Clearly, we need to gear up our science education to meet these challenges if we are to fully reap the benefits of the new economic policies.

At the same time, it seems very clear that the current state of university education in science, borrowed about a century ago from Britain and maintained essentially unchanged since then, is woefully inadequate to meet

this challenge. Indeed, the Chairman of the 1966 Education Commission, Dr D. S. Kothari, had forcefully expressed himself in the following words to the Minister for Education of the Government of India¹⁰:

'If I may say so, the single most important thing needed now is to get out of the rigidity of the present system. In the rapidly changing world of today, one thing is certain: yesterday's educational system will not meet today's, and even less so, the need of tomorrow'.

At a time when barriers between the traditional disciplines are breaking down, breadth and flexibility have to be key features of an educational system that expects to attract and retain gifted young people.

In suggesting possible solutions, the Panel discussed at length two crucial issues. One has to do with the apparently mutually incompatible demands for equity and excellence. The other has to do with the need to simultaneously provide adequate opportunities for both the small number of gifted students who may be able to enlarge the horizons of scientific knowledge, as well as the large number of students who need to be trained to contribute at diverse levels to the welfare of Indian society in an intelligent and competent way. The Academy has kept both these goals in mind in its proposals for improving the situation.

The Panel had extensive discussions on the issue of equity and excellence. It was unanimous in recognizing that this issue is an extremely complex one with far-reaching ramifications and room for a variety of points of view. This Paper places on record the Academy's general thinking on this matter, not so much with the aim of suggesting definitive solutions, but rather with that of initiating a debate on the issue among academics in the country. Such a debate on the seemingly incompatible twin desires for equity and excellence is essential, and should not be left merely to the politicians and the judiciary, as is currently the case. Perhaps the reason for the present state of affairs is that academics are, rightly or wrongly, perceived as being concerned only with excellence and ignoring the issue of equity. With such a prevailing perception, it is not difficult to see that political measures have been seen as the only method of promoting the cause of equity. The situation can only change if the academic community faces the real need for achieving both equity and excellence and suggests ways of doing so. Many academics have asserted that merit should be the sole criterion for admission to educational institutions. There is no denying that such a rigid rule will considerably disadvantage many potentially able people, at least at the present time. Conversely, laws are being enacted in the country to set aside quotas of various types. It is equally clear that beyond a certain level such reservations will be counter-productive in the long run and harm the country as a whole, including the very segments that need to be brought into the

country's social, educational and economic mainstream.

The important question is whether there is a way that would promote social justice and at the same time preserve academic values. One promising possibility is to reorient our thinking so that we would be able to view the whole issue as one of equity *and* excellence rather than one of equity *versus* excellence. It is essential to recognize that for a variety of historical and social reasons, a very large segment of our population aspires to a college degree. This aspiration has to be met. However, this need not mean that all these hundreds of thousands of students must enroll in the same few monolithic B Sc or B E degree programmes. The situation may be compared to that prevailing in the USA towards the end of the last century: by deliberate planning and conscious effort the system supported a few centres of high excellence *along with* a large number of universities that successfully provided education of value to the vast majority seeking it.

In our present situation, it is essential to completely revamp the fundamental structure of our university education system. We need to enlarge the educational opportunities by several orders of magnitude and create such a rich menu of possibilities and opportunities that the problem of providing for equity gradually disappears and becomes virtually irrelevant. We need to develop a large number of different kinds of flexible undergraduate degree courses that will permit the channelling of students according to their aptitude and motivation, without depriving any segment of society. One way to do this would be to have a large variety of undergraduate degrees in 'applied science', where the students get a thorough exposure to the fundamentals of different subjects such as Physics, Chemistry, Mathematics and Biology in the first year and then go on to learn specialized skills in chosen branches of science or technology. The system should also provide the flexibility for an individual to transfer from one institution to another, say after the first year, carrying credit for courses already taken, if such transfer helps fulfil the aspirations of the student in a better way. In this process, the advantages offered by distance education methods should also be exploited. When such a large and diverse set of opportunities does become available, the sensible thumb rule of using aptitude as the criterion for admission will, in all likelihood, cease to prove discriminatory towards anybody.

In the light of the above comments, the Council proposes to set up a special Committee to examine these issues in greater depth, and to advise the Academy on the role it can play in bringing about this transformation in attitudes. The Academy is convinced that such a reorientation in thinking is about the only way to achieve equity while at the same time ensuring the advance of science to serve the needs of the country.

The views expressed above, along with the realization

that different and appropriate strategies have to be planned for the large majority of students who need science education to run the country efficiently on the one hand, and those few who may take up careers in scientific research on the other, suggest that undergraduate education in science is best organized into three streams, to cater most effectively to the needs and aspirations of large numbers of young people. These might correspond, in purely organizational terms, to the framework proposed by the Planning Commission Working Group referred to earlier. In suggesting a *three-stream* system of education, this framework recognizes the need for adopting diverse strategies for achieving the objectives of the system. The comments made above regarding a rich and diverse menu of degrees in applied science are most appropriate to the third stream mentioned above. The more specific comments which are grouped below under two major headings apply largely to the first two streams of this initiative.

The Council's views on the functioning of Colleges and Universities, the roles of Government agencies, national laboratories and industry, are expressed through general recommendations in Section 5.

a) Patterns for undergraduate and postgraduate science education

At the undergraduate (UG) level the basic aim should be to make the spirit and excitement of science come through, so that appreciation for science would remain with the student independently of what he or she might do later. The UG course should be solid and broad based, providing a good foundation in at least two subjects, and should definitely avoid specialization too early. Thus all UG students should take some common courses in physics, chemistry, mathematics and biology in the first two years, or perhaps select combinations from a core curriculum so designed that they will be exposed to the fundamentals of these basic subjects; then choose subjects in one or two of the four streams for the third year. This will avoid variations in levels of teaching in the main and subsidiary subjects. One may reduce the content of each major subject, but no subject would be left out.

There is often a tendency to sacrifice essential areas of the four major subjects (P,C,M and B) to make room for trendy specializations such as industrial chemistry, theoretical computer science, and the like; or such 'job-oriented bio-courses' as poultry, fisheries, sericulture, etc. These can come later: early specialization at the UG stage must be strongly opposed, as it leaves the student with a weak conceptual foundation which is very difficult to make good later. This is especially true for those students who plan to go on to the postgraduate level and then possibly on to scientific research. For

genuinely job-oriented courses, such as the 'applied science' options referred to earlier, at least one year of good teaching of fundamentals is essential; this can then be followed by specializations like those mentioned above, and many others.

Curricula can never be static, and should be constantly reviewed and improved. In the process, room must always be made for really new subjects, but not at the expense of the foundational courses.

Experimental programmes should lay stress on open-ended exploratory experiments using simple materials where possible. Innovative experiments must be specially conceived and devised for this purpose.

At the post-graduate (PG) level, the first year should concentrate on the chosen subject with common courses for all students within that discipline. Further specialization, choice of elective courses, and project and seminar work should form part of the second year, and then preferably in the second term. It is common experience that industry also prefers students who have gone through a strong and common core curriculum, with no basic areas neglected, and with specialization coming towards the end of the PG course. For example the two year M Stat programme of the ISI is a successful, solid course which has an established reputation over the years for PG education in the mathematical sciences. It provides the right degree of flexibility and specialization in the second year of the course. Some other examples are the M Sc Courses in General Chemistry in some IITs and Central Universities. A similar approach would be most beneficial in all the other sciences.

With all four science subjects being offered to all students at the UG level for two years, we can hope to see such fruitful combinations of subjects as mathematics and biology or physics and biology being chosen by talented students at the later stages. The merging boundaries among different disciplines such as biology, chemistry, physics etc provide us with challenges as well as opportunities. These should be reflected in the course options available at advanced levels.

b) Comments relating to individual subjects

Mathematics: It is a fact that mathematics syllabi of most universities read very well on paper; and excellent texts in the various areas are now available at affordable prices in the country. The tragedy is the way in which the subjects are taught at the UG level, leading to poor inputs at the PG level and then at the research stage. Classical mathematics presented well at the UG level would be a fine beginning. What is important is to convey the spirit of mathematics, and to develop such core subjects as analysis, differential equations, algebra and probability and statistics on solid foundations.

As stated in (a) above, specializations should be taken

up only in the second year of the PG course, not earlier. There is also a general need to drop obsolete courses and improve the content of applied mathematics wherever it is offered.

Physics: The same weakness at the UG level seen in mathematics afflicts physics as well. We need more devoted UG teachers able to convey concepts and illustrate the unity of physics clearly. Such subjects as atomic and molecular physics and quantum mechanics often get short shrift in favour of various early specializations. At the PG level the core should consist of classical mechanics, classical electrodynamics, statistical thermodynamics and quantum mechanics, again with specialization only towards the end in the final term. At the PG level and later, physics students should preferably learn the mathematics they need from mathematicians. A major improvement is required in the way that laboratory training is imparted and the so-called practical classes are conducted.

Chemistry: The traditional division of this subject into inorganic, organic and physical chemistry has outlived its usefulness and is now doing more harm than good. It leads to loss of a sense of the unity of the subject, lack of appreciation of basic principles, and too early branching into narrow specializations. Starting from the UG stage, chemistry should be taught as based on the trinity of bonding, structure and reactivity. This is not an easy task, but at least at some universities in the country the effort to change in this direction must be made.

At the PG level the core in physical chemistry, for instance, should consist of thermodynamics, chemical dynamics, quantum chemistry and statistical mechanics. Also at the PG level, the interfaces of chemistry with biology and with physics should be brought out in some detail; and the transition from molecular to macroscopic behaviour made clear. The comments about laboratory exercises apply as strongly to chemistry as they do to physics. *Biology:* This is an extremely rapidly changing subject, which incidentally should be distinguished from biotechnology! An approach stressing unity in the various branches of the life sciences, both at the UG and PG levels, should be possible. Students of biology need to know allied subjects rather well. In this respect it is realized that many aspects of the subject can be learnt informally by motivated students on their own, while receiving more formal training in Physics, Chemistry and Mathematics.

5. Recommendations

The recommendations are presented here in two groups: first those that involve national bodies, agencies, the educational system, research laboratories and industry; second, those that depend mainly on initiatives to be taken by the Academy. Some overlap with the views

presented in Section 4 is retained to make the recommendations self-contained.

A. *General recommendations*

Functioning of colleges and universities, and role of national laboratories

The absolute minimum that students and society should demand from universities and colleges is that they run as announced in schedules, hold classes and examinations on time, and declare results on time. This can only be achieved by sustained pressure from students and the public, and removal of political influence on university functioning. Maintaining strict schedules will facilitate comprehensive and thorough coverage of material.

An important aspect is continuous teacher training and upgradation of knowledge through summer and refresher courses. Here the experience of the chain of Academic Staff Colleges has not been good. Attendance at these courses is used largely as a prerequisite for promotion, and only 15% to 20% of those who attend have serious interest in the subject. The selection of the participants is also generally not in the hands of the course organizers. Therefore, attendance at refresher courses and training programmes for teachers must be separated from promotions, and the organizers must be allowed to select participants as well as examine them at the end of each course.

Some of the proposals described in Section 3 involve creation of new institutions or centres. The Council strongly feels that these should be within the overall university system, but should be administratively independent and autonomous¹².

In particular, we urge the adoption of a three-stream approach to undergraduate education in science, in the spirit of the framework proposed by the Working Group of the Planning Commission, as described earlier in Section 3 (a) and 4. In the first two streams, leading to an improved B Sc degree and the B Sc (Hons) and the integrated M Sc degree programmes, the involvement of at least a few university departments in undergraduate teaching, in addition to their regular postgraduate teaching and research work, is essential; and such universities should offer all four of the basic subjects of Physics, Chemistry, Mathematics and Biology at similar levels. The course options for students in the third or Applied Science stream need to be drastically redesigned, so that apart from a foundation in basic science, a wide variety of options of a more vocational or practical nature are available; we are convinced that the traditional undergraduate course does not really address the needs of this group. Redesigning the undergraduate course on such lines will be a complex task, which could be the subject of future detailed discussions.

Along with the recommendation for the introduction of strong Integrated M Sc programmes in selected institutions, the Academy also urges the introduction of Integrated Ph D programmes in the four main science subjects. Such a scheme presently exists in Chemical Sciences, Physical Sciences and Biological Sciences at the Indian Institute of Science, Bangalore. Such programmes, the input to which would be gifted and motivated B Sc graduates, need to be very carefully structured and offered at a small number of select institutions capable of sustaining them.

In the Max Planck Institutes of Germany and CNRS in France, there is a tradition of scientists in national laboratories being given the opportunity to teach and interact with students at adjoining universities. In the process, such scientists are offered the academic title of Professor at the university. Such a relationship between universities and national laboratories makes eminent sense in our country today; already, as an example, one may mention courses taught jointly by scientists of the National Chemical Laboratory, Pune, and faculty of Poona University. At a more individual level, one should encourage the notion of adjunct faculty, which would enable outstanding scientists outside the university system to participate in teaching in universities. One step in this direction might be to create a fund to support teaching and research ventures undertaken jointly by faculty in universities and scientists in national laboratories.

Role of government agencies and industry

Looking at the present state of functioning of most of our universities, it is necessary for the UGC and Parliament to step in and make them more than mere examining bodies; instead they must be enabled to become centres of learning and excellence. To achieve this objective, funding provided to colleges and universities must improve, and at least at a few places quality science education centres must be started. One way to do so would be to implement the recommendations made by the Planning Commission Working Group, sketched in Section 3 (a). In addition, a system of accreditation of university science departments should be introduced; this should be carried out by a central and autonomous body not susceptible to local political pressures.

The efforts of DBT in the life sciences and NBHM in mathematics have been mentioned earlier. Other major agencies such as DAE, DOE, ISRO and DST must be persuaded to support selected, good M Sc programmes in physics, chemistry, biology and mathematics. The intention must be to support education in the basic sciences, not immediately linked to the needs of these agencies—such seemingly altruistic support will surely

help them in the long run. The institutions to be chosen for such agency support could be picked, on the basis of faculty and syllabi, by the Academy or any other body of standing. The agencies should provide scholarships, support setting up of laboratories, donate equipment, and do all this without insisting on too early specialization.

Industry too—the Confederation of Indian Industries (CII), the Federation of Indian Chambers of Commerce and Industry (FICCI) and the Associated Chambers of Commerce (ASSOCHAM) for example—should come forward with scholarships for PG students and support to laboratories. As is the practice in Germany, for instance, the chemical and pharmaceutical industries should be persuaded to give essential solvents and basic chemicals to UG and PG institutions for their chemistry programmes. In the same spirit, the Indian Chemical Manufacturers Association (ICMA) could be induced to provide help in improving education in chemical sciences. Groups of companies with common interests could also be targeted. Other sources, for example international bodies like UNESCO, could also be asked for similar support in all areas of science.

Wide publicity should be given to educational opportunities in the sciences, as well as to career opportunities in industry and elsewhere for science graduates. This could be done through the proposed new science magazine recommended below (in B (vi)).

B. Academy initiatives

Efforts by the Academy through the Fellowship

(i) The Council proposes to commission a group of Fellows to prepare two volumes on what students should know in each area of science respectively at the B Sc and M Sc levels, and as preparation for embarking on a Ph D programme. This last should be comparable to the level of attainment seen at the Ph D qualifying examinations of good US universities. The volumes may be brought out through private publishers under Academy auspices, and will reflect the suggestion made in Section 4 that for the first two years of B Sc all science students should have a largely common curriculum. Some description of course combination options and careers should be included.

(ii) The Council proposes to commission and support the writing of brief expository monographs ('appreciation courses') on scientific topics, in the style of the MIR publications of the former USSR. Some could be written by Fellows, some by others by invitation.

The Council also proposes to commission preparation of modern science texts at UG and PG levels as well as more informal Lecture Notes where necessary. In cases where classic texts are available in inexpensive

editions (many mathematics texts, the Feynman Physics lectures, etc.), the writing of supplementary texts leading up to the classics needs to be supported. Reprinting of other classics with permission, sometimes accompanied by commentaries, will also be encouraged.

Other types of monographs whose writing would be similarly encouraged are 'bridge courses', which would help non-experts get an overview of a scientific topic, and also advanced books on specific topics.

(iii) The Council plans to commission teams of Fellows to devise sets of experiments (say about a hundred) in each of the basic sciences, which bring out fundamental principles in an appealing way, wherever possible using inexpensive and commonly available materials.

(iv) In cooperation with experienced teachers and expositors, and working with existing centres such as the EMRCs at Pune and Hyderabad, the Academy will offer assistance in production of radio and TV programmes on science, and video tapes to supplement class room instruction at school and college levels. These could also be in regional languages, and explore 'alternative' methods of teaching. A library of 40–50 taped lectures, covering substantial parts of the undergraduate curriculum, could also be created.

(v) The Academy will attempt to periodically assess the state of affairs in education in each major scientific field and publish its findings, giving current trends, pointing out lacunae, highlighting possible opportunities, and offering suggestions about areas needing special effort.

(vi) *The Council proposes to launch a journal of science specially intended for science students and educated lay persons interested in science. The editorial, intellectual and financial backing of the Academy will be available to sustain such an effort. The journal will contain expository articles, descriptions of new teaching methods and innovative experiments, science news, historical notes etc. Information on course openings and facilities in various institutions might be included in such a journal, as well as advertisements from prospective employers of science graduates.*

Interaction with student and teacher communities

(i) Subject to the availability of resources, the Council will establish a programme wherein Fellows would be invited to identify one or two college students each year (within some overall limit) for placement in a (summer) programme organized or assisted by the Academy. Such students would be supported to spend some time – say two months or so – working and studying under a Fellow's guidance. Such short term research experience will help the student to use his or her spare time productively, and it is hoped that many bright youngsters may thereby be motivated into pursuing

careers in scientific research.

A similar programme at the college and school teacher levels is also being considered, with Academy support for summer training programmes for them. This will not be on the rigid lines of similar current programmes. The participants would be selected by the Academy on the strength of their motivation, rather than on seniority or as an aid to their promotion.

(ii) Similar to the series of Discussion Meetings supported by the Academy, the Council proposes a series of Academy seminars for chosen college teachers and promising students, which may be organized by groups of Fellows in each subject area. Students could speak to audiences of other students, teachers and Fellows on topics chosen with guidance. This would promote popularization of science as well as contacts between Fellows, students and teachers.

(iii) An Extension Lecture Programme, similar to the UGC supported programme at IISc for example, will be set up under Academy auspices. Fellows in each region would give lectures on a list of topics made available to nearby schools and colleges.

(iv) The Council proposes to invite a few college and university teachers to its annual and mid-year meetings as guest participants. This will increase personal contacts between Fellows and good teachers, and be a form of recognition for the latter.

The above initiatives demand linkages with reputed publishers and additional financial resources, which will be sought by the Academy from Government and private sources.

Link with teaching departments and institutions

Council recommends to University science departments and national laboratories that they produce brochures containing helpful information about their activities for the guidance of students. This is common practice in developed countries, but in contrast such information is rather difficult to obtain for a student interested in working in Indian institutions. The Academy could evolve a suitable format for such brochures, and assist when necessary in disseminating the information available in them.

Contacts with national bodies, agencies, etc.

(i) The Council proposes to set up a Committee to carefully examine the goals of equity and excellence from new perspectives, and to arrive at ways of restructuring the overall educational system so that these goals are no longer seen as mutually exclusive. The views of the Academy will be widely publicised, in the expectation that this debate takes a new and fruitful turn, showing us a way out of the corner into which the

country has pushed itself by so far relying solely on political and judicial approaches.

(ii) The Academy expresses strong support for the Integrated M Sc programmes along the lines described in Section 3. The Academy is willing to offer its assistance in the selection of institutions to establish such programmes and in the preparation of appropriate syllabi, including experiments.

The Academy also recommends the setting up of Integrated Ph D programmes at a few select institutions, which would take students with a good undergraduate degree and give them the necessary training (including course work) to bring them to the threshold of research. Suitable guidance could then be offered to enable them to work towards a Ph D. A Master's degree could also be awarded at a suitable intermediate stage.

It is also recommended that the usual Ph D programmes, which take students after a Master's degree, should include some pre-Ph D courses to bring students up to the same level as in the Integrated Ph D programme. In some of the advanced courses offered in the integrated programmes or as part of the requirements for the Ph D programmes, students from different institutions may be pooled together, especially when the numbers involved at each institution are small.

While the above recommendations relate to research level training in science, the Academy strongly endorses the pattern of UG science education as outlined in Section 4(a).

(iii) The Academy also endorses the need to introduce special M Sc courses in different branches of science, in the spirit of the DBT programme. It is recommended that the science departments and agencies of the Central Government provide scholarships to such students and support the setting up of laboratories and other facilities for such courses.

(iv) The views of the Academy on the structure and content of science education at the UG and PG levels, as suggested in Section 4, and on the support needed by universities and colleges as well as on the way they should function, will be made widely known to the general public, the student and teacher communities, other academic societies, and Government bodies such as the Planning Commission, the Department of Education, and the UGC.

6. Summary of recommendations

General recommendations

Functioning of colleges and universities

- Universities and colleges should satisfy the minimum requirement of running on schedule in all respects.
- Properly implemented continuous teacher training pro-

grammes must be established.

- Council endorses the recommendations of the Planning Commission Working Group, described in Section 3 (a), with the modifications suggested in the text.
- It is urged that new institutions or centres created should be within the overall university system, but administratively independent and autonomous.
- Academic cooperation between educational institutions and national laboratories should be strongly encouraged, including joint research, teaching and adjunct positions.

Role of Government agencies and industry

- Funding of colleges and universities must improve, and quality science education centres should be started at a few places at least.
- Accreditation of science departments in universities and colleges, to be reviewed periodically, should be carried out by an autonomous central body.
- The pioneering efforts of DBT in the life sciences, and NBHM in mathematics, should be expanded upon and emulated by other major agencies such as DAE, DOE, ISRO and DST; these agencies should support selected M Sc programmes in basic sciences, without early specialization.
- Individual industries and industry associations with common interests should award scholarships at the PG level, and support laboratories with funds and supplies. International agencies like UNESCO should also be approached for similar support.
- Wide publicity should be given to all educational opportunities, and to career opportunities in industry and elsewhere for science degree holders.

Academy initiatives

Efforts by the Academy through the Fellowship

- An Academy Committee will be set up to study how the twin aims of equity and excellence may be achieved by a suitably reoriented system of science education.
- The Academy will commission the preparation of two volumes to indicate what the desirable levels are in each area of science for a student at the B Sc and M Sc levels, and at the threshold of research. The volumes could also describe course combinations and careers.
- The Academy will commission the writing of monographs and lecture notes as necessary at different levels.
- The Academy will commission documentation on 100 experiments in each of the basic sciences, using inexpensive commonly available materials, with the

objective of bringing out principles in an appealing way.

- The Academy will cooperate with or sponsor production of science programmes using the electronic media, possibly also in regional languages and using 'alternative' teaching methods.
- The Academy will periodically assess the state of affairs in the country in each of the basic sciences, and publish its findings, along with recommendations as to where special efforts are needed.
- The Academy proposes to launch a new journal accessible to university students and teachers in science and the educated lay public interested in science, featuring expository articles, description of new teaching methods and innovative experiments, science news, historical notes, etc.; the journal will contain advertisements from prospective employers, and information about opportunities for study and research.

Interaction with the student and teacher communities

- A scheme for placement of students with Fellows of the Academy for summer research programmes will be worked out. A similar programme will be undertaken for association of motivated college and school teachers.
- A series of Academy seminars will be organized involving selected college teachers and promising students, on topics chosen with the guidance of Fellows.
- An extension lecture programme in different regions with the cooperation of local colleges will be set up under Academy auspices.
- The Academy will invite selected college and university teachers to its annual and mid-year meetings as guest participants.

Link with teaching departments and institutions

- The Academy will encourage university science departments and national laboratories to produce brochures containing helpful information for the guidance of students.

Contacts with national bodies, agencies, etc.

- The Academy supports the introduction of a wide variety of undergraduate applied science courses, undergraduate science programmes of high quality in selected institutions, and Integrated M Sc programmes. At least a few of the undergraduate science programmes should be run at University Departments where postgraduate courses are also conducted, and not only at affiliated colleges. The Academy also recommends the setting up of Integrated Ph D programmes in selected institutions, with a suitable course programme

as an integral part.

- The Academy endorses the need for good M Sc courses in different branches of science, similar to the DBT programme.

List of panel members

1. V. G. Bhide, Department of Physics, University of Poona, Pune
2. J. Chandrasekhar, Department of Organic Chemistry, Indian Institute of Science, Bangalore
3. M. K. Chandrashekar, School of Biological Sciences, Madurai Kamaraj University, Madurai
4. S. Datta Gupta, School of Physical Sciences, Jawaharlal Nehru Centre, New Delhi
5. B. M. Deb, Department of Chemistry, Panjab University, Chandigarh
6. R. Gadagkar, Centre for Ecological Sciences, Indian Institute of Science, Bangalore
7. N. Mukunda, Centre for Theoretical Studies, Indian Institute of Science, Bangalore (Chairman)
8. A. Sitaram, Indian Statistical Institute, Bangalore
9. V. Srinivas, School of Mathematics, Tata Institute of Fundamental Research, Bombay
10. R. Srinivasan, Inter University Consortium for DAE Facilities, Indore

11. M. Vidyasagar, Center for Artificial Intelligence and Robotics, Bangalore

1. *Statistical Outline of India: 1988-89*, Tata Press, Bombay.
2. *National Policy on Education*, Ministry of Human Resource Development, Government of India, 1986.
3. This is an annual average from the total 8th Plan outlay on school education. See, for instance, *Journal of Educational Planning and Administration*, 1993, 7, 18.
4. Report of the Working Group constituted by the Planning Commission to suggest ways and means to improve undergraduate courses in science at Indian Universities, 1989.
5. Kumar, A. and Nigavekar, A. S. on 'Physics Education' in *Physics in India* (ed. Jha, S. S.) Diamond Jubilee Publication, INSA, New Delhi, 1994, chapter 2, pp 13-35.
6. Reports of the Curriculum Development Centres, University Grants Commission (1991).
7. Deb, B. M., *Curr. Sci.*, 1994, 67, 427.
8. *Curr. Sci.*, 1992, 63, 270.
9. 'Reforms in our Universities: A New Perspective', A Report submitted to the Governor of Maharashtra, March 1993.
10. The Report of the University Education Commission (December 1948-August 1949), Government of India Press, Simla, 1949.
11. Report of the Education Commission 1964-1966, Government of India Press, Delhi, 1966.
12. After preparation of this document, there has been considerable discussion of a proposal to set up a National Science University (NSU), (cf *Current Science*, 1994, 67, 502-519. In Council's view, the proposals contained in the present document are wider in scope, more feasible, and take into account all aspects of this situation in a balanced way.

The ascent of molecular cardiology

C. C. Kartha and O. M. Najeeb

The techniques of molecular biology are increasingly employed to delineate the molecular basis of both normal and abnormal cardiovascular function. Thanks to the knowledge gained in these realms, remarkable progress has been made in recent years to understand the cellular and molecular mechanisms of diseases of the heart and blood vessels. Novel therapeutic options are also on the horizon. This article highlights the major advances made in the field of molecular cardiology.

THE year 1628 is a milestone in the history of medicine. It was then that a physician in St. Bartholomew's Hospital, London, William Harvey, demonstrated the function of the heart and circulation of blood using quantitative experimental methods. That marked the beginning of cardiology. Harvey's revolutionary ideas

did not immediately lead to dramatic changes in either the diagnosis or treatment of heart diseases. Three hundred years elapsed before a second revolution transformed the practice of cardiology. The golden age in the discipline was heralded by the invention of the electrocardiogram by William Einthoven. The four decades that followed witnessed a technological explosion which led to newer diagnostic methods involving catheterization techniques and application of the ultrasound. In the field of treatment, the invention of the heart-lung machine opened up new avenues for the

C. C. Kartha and O. M. Najeeb are in the Division of Cellular and Molecular Cardiology, and Department of Cardiology, Sree Chitra Tirunal Institute for Medical Sciences and Technology, Thiruvananthapuram 695 011, India.