Patterns and priorities in Indian research and development*

R. Chidambaram

It is necessary to reverse the current trend of diminishing attraction for careers in R&D by providing a guaranteed career profile to the highly talented students on completion of the 10 + 2 stage. Simultaneously a new educational model with liberal funding of selected high-quality post-graduate University Departments is needed. The most gifted scientific leaders must be adequately supported and areas of high priority, which should include globally competitive basic research, must be carefully selected. An analysis of the patterns in Indian R&D is attempted. It is also imperative to strengthen the University R&D system and to increase its synergy with the National Laboratory System.

ONE of the problems causing great concern in the present day science and technology (S&T) scenario of the country is the diminished attraction for careers in research and development. In recent years, IITs are getting fewer students for Ph D programmes in mathematics and physics. Students who win medals in Mathematics Olympiads rarely take up careers in mathematics. Even in a popular subject like computer science, a job rather than a career in research is preferred today. In engineering research, the trend, even earlier, has been to avoid hardware-oriented projects. We must find methods of reversing this trend, since India today needs S&T to improve the quality of life of its citizens, perhaps needs them more than the developed countries where the quality of life is already high.

Indians feel proud when there are achievements in basic research of a high order like the work of Srinivasa Ramanujan, C. V. Raman, S. Chandrasekhar, S. N. Bose, M. N. Saha or Hargobind Khorana. These are men who charted their own scientific paths. Indians also feel proud when there are technological achievements of a high order like the commissioning of a nuclear power plant or carrying out nuclear tests, putting a satellite into orbit or successful test launching of a missile.

Generally, the development of indigenous instruments for research, which is extremely important for laying a strong foundation for future R&D in physics and chemistry, does not claim as much appreciation, even among scientists, as good research carried out with imported instruments. In contrast, however, one of the strengths of the Department of Atomic Energy (DAE) has been its emphasis on the development of indigenous instrumentation, whether it relates to power reactor control or research reactor utilization or any other field in which DAE is involved. Indeed our country must encourage the development of indigenous hi-tech instruments, which will strengthen our self-reliance. We must also learn to appreciate achievements in applied research and technology development, particularly in engineering disciplines, which generate national wealth. The attitudes reflected in the value system in Indian science, and in its recognition of achievements through fellowships in science academies or through awards, also perhaps need a change. The scientific associations and societies in specialist disciplines and some foundations are, however, providing recognition for achievements of the type I mentioned earlier in this paragraph, and this should be encouraged to grow. We must strengthen self-reliance as well. I remember that in my younger days, at the Indian Institute of Science, in the late fifties, when we constructed a voltage-stabilized power supply for the first time, we felt happy. The commissioning of the first indigenously built nuclear research reactor, *APSARA*, in Trombay in 1956 (incidentally, the first reactor in Asia), was a great national achievement. Today, four decades later, any product which we develop – whether it is a drug, a car or a reactor – should compare favourably with a similar product available elsewhere in the world, both in quality and price. That is why today I no longer consider self-reliance as equivalent to self-sufficiency. If something is available to us from abroad much cheaper or of much better quality than that of a local product – particularly if it is to be integrated into a larger complex system – we should import it. But, if something is denied to us, we should have the capability to develop and manufacture it ourselves. Thus, I define self-reliance, today, as immunity against technology denial.

R. Chidambaram is at Department of Atomic Energy, Anushakti Bhavan, Chhatrapati Shivaji Maharaj Marg, Mumbai 400 001, India.

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India is a large country, and therefore it should be present in every frontier area of science and of high technology. But how much we invest in each area, at any point of time, requires careful and wise analysis taking our national interests into account. Frederick Seitz[1] says: 'The advance of science requires money given with appreciation and wisdom, but the amounts must be determined by many complex factors ...'. There are areas like thermonuclear fusion, which are clearly important for the future, but where it is difficult to predict when it will become a practical technology. For instance, we cannot invest billions of dollars like the developed countries are doing in the International Thermonuclear Experimental Reactor (ITER) project, but, nevertheless, we should be in the game; that is why the Government is supporting the Superconducting Steady State Tokamak project in the Institute for Plasma Research of DAE. For India, as for the rest of the world, materials technology and information technology will gain increasing importance. Agriculture, biology and medicine will move to the centre stage of R&D, with a particular focus on the gene. Apart from national security from a military point of view, we also need food security and health security for the citizens of this country.

An important factor which influences the pursuit of R&D in India is what I have called many years back[2] as 'Velocity of R&D'. This is a relative velocity, and is a ratio of the time our peers abroad take to complete an R&D project in a frontier area of S&T and the time we take to complete a similar project. Though things have improved considerably over the last couple of decades, our velocity of R&D is still lower than that in a developed country. There are many reasons for this, including infrastructure weaknesses, communication inadequacies, bureaucratic delays, non-availability of industrial products from local sources, insufficient access to scientific literature, lack of adequate peer groups, inadequate synergy between the National Laboratory System and the University System, etc. but the important fact is that things are improving in the country across-the-board. When the velocity of our R&D comes on par with that in the developed countries, India will see spectacular technology growth and we should all work towards that.

Young students will be attracted to research only if they are convinced that they would be working on 'important' problems; Peter Medawar[3] said: 'It is not enough that a problem should be "interesting" – almost any problem is interesting if studied in sufficient depth ... the problem must be such that it *matters* what the answer is – whether to science generally or to mankind'. There is no easy prescription to define the importance of an R&D problem. For example, after giving several lectures on your work, if you find that hardly anybody asks you a question, you should begin to worry about the importance of what you are doing. Similarly, flogging a field which was important many years back, or hanging on to the coat tails of a currently fashionable field and basking in the glory of the field rather than your own contributions, are also some of the temptations to be avoided. Furthermore, 'safe' research problems with guaranteed results cannot excite the brightest among young people. It is an established fact that challenge in any area is related to the accompanying risk, although highly challenging problems never fail altogether, and may, in fact, lead to unexpected successes in an altogether different direction. The young people's reaction to science is a reflection of the attitude of the already established and influential scientists, and, consequently, I feel that the latter must avoid cynical and pessimistic statements – however well-intentioned, but, in my opinion, often inaccurate – about the current state of Indian science. If talented young people find challenging scientific careers in India, there will be less temptation for them to go abroad and settle down there, although experience gained abroad in advanced areas of S&T is valuable. To me, therefore, the ideal situation seems to be that the scientist (or technologist) gets a permanent position in India, afterwards goes abroad for a reasonable period (up to a year or even two years if it is the first time abroad), and then works here for several years (say, six years) before his next visit. I am not including here short visits for scientific meetings. The emotional, cultural and spiritual attachment of Indians to their country is an advantage in this context. I also used to tell my students that the best thing that happens when you go abroad to a developed country for the first time is that you realize that 'they' are not smarter than you!

We must not lose sight of the imperative need to raise the quality of life of the common man in the country. We have also to ensure national security. Thus, opportunities for growth and development exist in a variety of areas as well as in a variety of disciplines; all having exciting problems that need to be tackled as well as requiring people of high talent, though individual tastes may favour pursuit of one problem over another.

A good part of our R&D must correlate with our natural resources so that we can take advantage of our minerals, our coastline, our sunshine and our rainfall. India has done well in many fields, and if we choose our priorities right and if we fund the correct field wisely, I am confident that India will show dramatic improvement in terms of R&D achievements in the future.

The research problems of many scientists in pure sciences are linked with those of peers abroad, and this is desirable to keep pace with developments in S&T. However, it is necessary for a scientist to voluntarily put a limit on such contacts abroad and avoid addiction to advanced research facilities outside India so that his or her work within the country is not affected by sanctions of developed countries, if such sanctions do emerge at some later time. But, we should work towards integrating ourselves into international science in such a way that any imposed sanction would equally affect both the parties.

This would be a strong disincentive for contemplating imposition of such sanctions by developed countries. Thus, international collaboration should progressively make us less, and not more vulnerable to outside pressures.

It would be useful to analyse here the types of R&D currently being pursued in India within the framework I have described earlier. However, it must be realized that the validity of the concept of an innovative chain of basic research leading to related applied research and then on to development of a product or a process within a confined environment is no longer valid, because of extensive and immediate information diffusion. Many industrial laboratories in the West are questioning the need for funding basic research within their system because of this reason. When the results of basic research done elsewhere are easily available, they feel they can concentrate on applied research after making an appropriate selection. When I was the Director of BARC in the early 1990s, I had suggested to my colleagues that our motto for project selection should be 'Relevance or Excellence, preferably both', the reference of relevance being to the mandate of DAE. In this connection some of the other questions I would raise are: Why is this project 'important'? How does it relate to national development – in the broadest sense? Are you making use of DAE's synergistic strengths? In any programme of a mission-oriented agency, like DAE, there has to be a balance between risk and restraint. In big high-technology projects, you cannot risk more than you can afford to lose; whereas, in R&D projects you should go for the jackpot! Since then my ideas have undergone further crystallization, and my aim in this article is to consider the broader issue of patterns and priorities in R&D on a national scale.

In this article, I shall address several other important questions as well: How to raise the level of technology in India so that it is on par with the best in the world? How to involve the university system more and more in every kind of R&D work of high priority and how to change the Government-funded education system so that it guarantees career avenues to highly talented students? The latter would require nucleation of a new educational model. I shall also examine the role of synergy among S&T institutions in achieving these goals.

Types of R&D in India

I classify below the R&D work done in India today into several categories:

Basic research

Any civilized country should encourage its intellectuals to ask questions about nature and to participate in the worldwide search for solutions to the mysteries of nature. Such problems, for example, include trying to find out about the ultimate structure of matter or the origin of the Universe; such problems can be pursued in almost every discipline, including the engineering disciplines. This is a cultural necessity. India should provide opportunity to its greatest minds to work on important fundamental problems of their choice. I would consider such work, which is best carried out in a university environment, to be of the highest priority, if it is globally competitive. Basic research is also important to a mission-oriented agency like the DAE because knowledge gained from basic research is the foundation upon which the structure of frontier, continuously evolving technologies, like the nuclear technology, can be built.

The Indian University system is too large and of too heterogeneous a quality. Thus, a high level of support to all the basic research groups in all the universities is neither financially feasible nor would it produce the desired results. Therefore, the University Grants Commission (UGC) and the Department of Science and Technology (DST) have several ongoing programmes to selectively support groups of exceptional merit, which should be strengthened. The national laboratories and the mission-oriented agencies must also use the capabilities of these (basic) research groups in their applied research and technology development tasks.

International co-operation, exchange visits, and sharing of advanced research facilities with peers abroad should be encouraged; but a strong home base is necessary. Sometimes high technology is catalysed by basic research. For example, laboratory automation got a big fillip through the design of diffractometers in crystallography research. From the laboratory, an instrument goes on to become commercial; if one buys only 'proven' commercial instruments, he or she is guaranteed to receive obsolete though useful technology. On the other hand, it is valuable to be present where such a development is taking place; I was present in the Oak Ridge National Laboratory when the first computer-controlled X-ray diffractometer in the world was being developed in 1964, and this was helpful in our development of automatic neutron diffractometers for use in the research reactors in Trombay.

Participation in international mega-science projects is also very desirable, but this should be on an 'equal partner' basis. It is often not realized[4] that sometimes the highest level technologies are introduced in basic research projects: for example in the Large Hadron Collider (LHC), which is being built by the European Organization for Nuclear Research (CERN) in Geneva, and in which we are participating, to answer fundamental questions related to the ultimate structure of matter, and such joint participations are sure to have technological spin-off benefits for any country, whether it is USA, Japan or India.

LHC is likely to be the most powerful accelerator ever built and will cost two-and-a-half billion dollars, and DAE has agreed to contribute, in kind, twenty-five million dollars (estimated at European cost; though our actual cost will be half of this or less) spread over eight years or so. An example is the superconducting sextupole magnets which are being jointly developed by the Centre for Advanced Technology, at Indore, and CERN; wherein more than a thousand magnets, built by India, will be used to focus the beam around its 26 km path. Half of our contribution will be towards the LHC construction and the other half will be kept in an 'India fund' controlled by us to support *inter alia* our scientists, including those from the university system, who are collaborating with international teams on the construction of two mammoth detectors (ALICE and CMS) and will later on carry out experiments with the LHC. DAE and DST are jointly supporting the detector designs and the experimental programme.

Mission-oriented applied research and technology development

There are large national missions related to the development of indigenous capability in high technology fields like nuclear power, nuclear weapons, missiles or satellites. Building large systems like a fast breeder reactor, a synchrotron radiation source, a superconducting cyclotron accelerator, a superconducting steady state tokamak for thermonuclear fusion research, a geostationary satellite launch vehicle (GSLV) or a long-range ballistic missile requires system integration of subsystems based on a wide range of technologies and expertise in many science disciplines. Large national missions feed directly into national development and national security and are essential for a modern state. I would place this kind of work in the high-priority category, more so when we are a target of technology-control regimes.

Homi Bhabha's vision, in the early forties, to start a self-reliant nuclear programme has not only been realized but has laid the foundation for other mission-oriented programmes in the country. He had the courage and the confidence in his countrymen to start the Tata Institute of Fundamental Research to develop indigenous expertise needed for our nuclear programme, for which he wrote to J. R. D. Tata in 1943. His farsightedness lay in the fact that, in this process, he also nucleated outstanding research groups in areas which were not directly related to nuclear technology like pure mathematics and molecular biology, which have impacted greatly the progress of science in the country.

India, today, has practically every kind of S&T institution, and synergy among these institutions would help in rapid national development. Synergy is an economical and efficient option, and, perhaps, the only option for rapid national development today. Any agency that requires results which are based on some specialized research, does not have to set-up a new laboratory or a new institute, and, more than that, does not have to hunt for specialists in that particular area; if such a know-how or capability exists within India, it should be utilized. One approach for carrying out such a focused applied research programme could be through setting up of joint centres in universities or IITs by mission-oriented agencies. Another approach used for carrying out such a focused applied research programme was the recent collaborative project between the M. S. Swaminathan Research Foundation and the DAE on the use of nuclear and biotechnological tools in coastal areas near nuclear power plants in Tamil Nadu, with the aim of improving the livelihood of the people in the neighbourhood. I consider such synergistic interactions among institutions to be of high priority and these are fortunately getting stronger in the country. I must also mention here that DAE and UGC joined together a decade back to set up the Inter-University Consortium for using major DAE facilities like the *DHRUVA* reactor, the cyclotron at Calcutta, and the Synchrotron Radiation Source at Indore. Based on this trend, therefore, one can foresee that perhaps in the future large national laboratories will be run by a consortium of Indian universities along the lines of the Associated Universities, Inc., in the USA, managing the Brookhaven National Laboratory or the Argonne National Laboratory.

There is a kind of research which is more prevalent in a mission-oriented agency which has a strong basic component, but the know-how can be transferred to applied research in a needed area. There are numerous examples from our atomic energy programme, particularly in the physics, chemistry and materials science areas. In my own work, high pressure research is of great basic research interest in phase transformations in materials, but is also related to nuclear weapons research. For example, in a fission device, which is based on implosion, the shock equation of state of plutonium, as well as of the surrounding materials, has to be precisely known if one has to make an accurate estimation of the device's explosive yield. Similarly, in developing the phenomenology of underground nuclear explosions and choosing the emplacement depth to prevent the release of radioactivity, it is necessary to follow the shock wave propagation through a computer simulation program after inputting the complex physical properties of the rock medium. In any major development effort, which involves applied research and technology development, it is essential to have, in close proximity, experts in basic research so that expected or, more importantly, unexpected gaps in knowledge can be filled. This was true for both the Manhattan project and our own Pokaran tests.

Country-specific applied research

This relates directly to the national needs of our country, and are specific to the conditions prevailing here, and, therefore, I am placing it in a separate category, though some of these projects could indeed be called mission-oriented. Examples being: research in field of agriculture, on diseases endemic to India; or on prediction of the Indian monsoon, etc. This kind of R&D addresses problems which may not interest the rest of the world, but are of highest priority for us. The highly successful Green Revolution initiated three decades back is an example of this type of R&D.

Industry-oriented R&D

Homi Bhabha[5], in his famous speech to the International Council of Scientific Unions, emphasized the need for developing countries to go towards an 'economy based on modern technology'. Indian products as well as their export should maximize value-addition to conventional resources, and India should rely increasingly on knowledge-based industries. And all these require industry-oriented R&D and a rapid expansion of the culture of patenting to protect our intellectual property rights (IPR). Newly industrializing countries have also to be conscious of environment protection, a concern which was absent in the early days of industrialization in the Western countries. This should be treated as a blessing rather than a handicap. If technology does not change, installing a new plant may, of course, make a product costlier than what is produced from an old depreciated plant. But, by and large, new technology should make a product cheaper. It also provides us with an opportunity to leap-frog in technology, backed by fresh R&D efforts.

There are laboratories which carry out R&D related to the needs of a company or a specific industry, both in terms of developing the technology which can then be transferred, and later of updating it and of solving problems encountered in production. Nayudamma's work in the Central Leather Research Institute of CSIR, for example, has had a tremendous impact on leather technology. Chemical and pharmaceutical industries have, over several decades, benefited from Indian R&D. In particular, important contributions have been made by the University Department of Chemical Technology in Mumbai and by the National Chemical Laboratory of CSIR at Pune. The dependence of the Indian pharmaceutical industry on Indian R&D will increase in the future as our drug companies seek to develop their own proprietary 'molecules'.

There is a strong need to strengthen this kind of R&D as well as to have more university laboratories, apart from CSIR and other national laboratories, to take up industry-oriented R&D. National laboratories can act as an interface between the university system and the industry system. As India increasingly becomes globally competitive, technology will be denied more and more for commercial reasons, like it is being done today in strategic areas. IPR issues will become progressively more significant; the result will be that Indian industry will increase its interactions with indigenous R&D.

Some companies have their own R&D laboratories which are valuable for problem-solving, though sometimes the problems solved are superficial and merely relate to attracting consumers. This is inevitable because demand for R&D inputs in industry will be driven by market forces. Better trends are, however, emerging in the country, particularly in the pharmaceutical and computer industries. Link-up with the national laboratories and the university system through sponsored R&D and consultancy is essential for strengthening the in-house effort. Industrial companies should also take advantage of the fact that information dissemination at the international level is liberal among basic research scientists; information doors begin to close in applied research and are firmly shut when technology development starts. It would be useful for Indian companies, particularly in the pharmaceutical, biotechnology, computer and opto-electronics industries, to *now* sponsor post-doctoral candidates for basic research in universities abroad (in areas of the companies' choice) and hire them afterwards to get up-to-date knowledge of developments around the world. A number of industry associations are also there in India and they carry out research in specific industry areas and are useful. There are some newly emerging areas like genetically engineered agricultural products, where the profit possibilities are very high, in which in-house R&D may become significant.

Parasitic research

If research, which appears to be important because it follows global trends, is pursued with excessive foreign contacts and collaboration, without original ideas coming from India, it tends to depend on foreign patronage. It also leads to complaints that India is falling behind the West in experimental facilities, with the consequential necessity to depend excessively on advanced facilities abroad. One wonders how such research – except in rare cases – can be important to the country? Benefits of such research, if at all, are likely to feed foreign technology and the students trained in such areas tend to go abroad immediately after their Ph D. Such parasitic research should be given low priority. It should be emphasized again that international scientific cooperation is important, but today's India should not go for it on a 'donor–recipient' basis.

Research for teaching improvement

If a university teacher is an excellent researcher as well, it is indeed an ideal situation: There are several such examples in the present Indian university system.

Furthermore, we should also respect a scholar who can understand the latest developments in the subject he teaches (without doing any research himself), and is a good communicator as well. But 'compulsory' research for short specific periods by reluctant college teachers to improve their promotion prospects seems to be of doubtful utility even if the teacher is motivated enough to try to continue his research in the place to which he returns, since many colleges lack the necessary infrastructural and other support.

Direction-less applied research

Sometimes a piece of applied research is pursued indefinitely without linking up with an end user. This seems to be entirely purposeless and leads only to frustration in the group, followed by degradation of the know-how developed after some time. In my opinion, such research should be abandoned if a suitable industrial or other end user is not found in time.

Conclusions

Kameshwar Wali[6], in his biography of the great astrophysicist Chandrasekhar, reports on the latter's explanation of the remarkable fact that in India, in the 1920s there were several scientists of international reputation like Ramanujan, Raman, Saha and Bose. Chandrasekhar says: 'I myself have associated this remarkable phenomenon with the need for self-expression, which became a dominant motive among the young during the national movement. It was a part of the national movement to assert oneself. India was a subject country, but in the sciences, in the arts, particularly in science, we could show the West in their own realm that we were equal to them'. The same is true for Chandrasekhar himself. Today, more than fifty years after Independence, the motivation for doing science must be to make India into a 'developed' country, which would include raising the quality of life in rural India to the level prevailing in the non-urban areas of already-developed countries.

Most of the support for R&D in India at present comes from the Government, though, as India develops, industry support to R&D will increase. The latter will have a strong impact on the speed of technology development in the country, but will be directed towards profit growth and not explicitly towards national goals. That is why I will concentrate now on Government support for R&D projects which, I think, should be on the basis of any, or a combination of the following criteria (not listed in order of priority):

(i) it should improve the quality of life, particularly health, of Indians;
(ii) it should lead to generation of national wealth;
(iii) it should enhance national security;
(iv) it should prepare the country for developments which could later lead to one of the above three criteria;
(v) it should increase the global competitiveness of our products by focusing on our strengths – our natural resources and our human talent;
(vi) it should improve the quality of education;
(vii) it should permit the highest intellects to pursue important fundamental problems of their choice.

Difficult choices will have to be made among different fields of science and technology, and among institutions; it is surely not unfair – when funds are limited – to ask if the funds sought for R&D in a particular field by an institution could not be more gainfully spent on a different field by another institution. Leading basic research scientists must be supported in the fields of their choice; only some caution is needed in terms of the number of doctoral students they train, to prevent distorting the R&D priorities in the national context. When one is developing a new area, there are two options that are available: either one plans the programme, constructs the laboratories and then brings in a suitable person to lead the programme, or, alternatively, one selects the potential leader and then allows him to nucleate the programme and grow it. The advantage of the latter option – originated by Bhabha – is that the scientist grows with the programme and the available resources are optimally utilized. There are outstanding examples of this among the institutions of the DAE.

On a more general level, existing evidence does show a correlation between growth of GNP in a country and the percentage of GNP devoted to R&D in that country but the correlation can only be valid if the distribution of funds among various disciplines and projects is done with GNP growth as an objective.

There are limitations to central planning and the funding mechanisms should have the flexibility to accommodate differing perceptions. The peer review system for funding of R&D projects by DST and other departments is, I think, generally satisfactory, when the projects are small (costing less than, say, Rs 50 lakh or even a crore). However, new mechanisms, both in the funding agencies and in the Planning Commission, will have to be devised if important facilities, costing tens of crores of rupees and more, say, a large accelerator, are proposed to be set up in a university or in an inter-university centre. This is also true for areas like the human genome programme or the design of DNA chips to find the genetic basis of diseases.

There should be sufficient decentralization in decision-making, once the funds have been allotted, to maximize creativity and efficiency and to minimize procedural delays. We must try to ensure that the best scientific leaders are engaged either in the pursuit of important fundamental problems or in high priority areas of national importance. Then only the latter will attract motivated young research workers. Thus, we would be strengthening scientific tradition, already built up in the country to some extent, and at the same time, we would be distributing available funds to high priority areas.

A majority of persons taking up R&D careers today in India seek job security and that is one of the reasons why the BARC Training School programme, which provides such job security, has been so successful for more than four decades. The current trend in recent years has been in the appointment of the products of our training school as the directors and chief executives of our DAE units. The system of the BARC Training School, which involves selecting a few persons and then training them in advanced S&T areas rather than training a large number of people in such areas and selecting a few from among those trained, has been found to be economical and effective and, in my opinion, should be adopted by other large scientific organizations as well.

Financial security is necessary but not sufficient in itself. The S&T environment in the country, the working environment in the scientific institutions coupled with effective leadership must enable the potential of the scientists to be fully actualized. The leadership has to be both at the group level and at the institution level to ensure that group tasks are fully achieved, on the one hand, and the needs of the individual scientists are met, on the other. Scientific leaders are either contemplative thinkers or those who get things done, i.e. either are yogis or commissars, though every one of them is perhaps a mix, with one of the characteristics predominating. Very rarely does one come across a scientific leader like Homi Bhabha in whom both these characteristics were developed to their maximum. The scientific and political environment in the country must be built up to allow many more such scientific leaders to develop.

There is a curious situation existing in the country. On the one hand, the number of people being given post-graduate degrees in science disciplines, without an appreciation of their possible future careers, is much too large: the dilution of resources that this infructous training represents has the consequence of deteriorating the quality of the training for the really talented people. On the other hand, there is a considerable reduction in the number of such talented and motivated students seeking admissions to science courses. This phenomenon is widespread all over the country and can seriously hurt the supply of good scientists for manning scientific institutions and universities in the coming years. The solution lies in selecting the post-graduate students carefully and funding science departments in universities selectively, but adequately, in fact liberally, particularly from the point of view of establishing good experimental facilities within the universities (which should be freely accessible to the students) and also advanced facilities in national laboratories being made available to them for project work. Implementation of this solution will involve two steps: predicting the demand for post-graduate students in each discipline a few years hence; and disbanding ill-equipped superfluous courses.

It is on completing the 10 + 2 stage that a young man or woman takes a decision regarding his or her career. The tendency nowadays is to go abroad or go in for a paying job instead of a research career, even though the young person is highly talented in science. This is because of family pressures and influence of peer behaviour. The solution is to guarantee a career profile to such a talented person, if he/she sticks to a research career in India—a guarantee which, in my opinion, should start through his/her college years and extend till superannuation. I would suggest a career profile which is financially equivalent to, in the absence of an easily definable better criterion, that of an IAS officer. We can put milestones in the research career to ensure that creativity and originality persist, but the guarantee of the career profile should be independent of the place of work – a college, a university or a national laboratory. There will be no compulsion to stay with the scheme and the person will be free at any point to opt out without penalty and take up any alternative job or career. This experiment must start with mathematics, which will also cost the least, and can then be extended to other disciplines. In the case of mathematics, if 5 or 6 talented students are picked up every year (say, all those who win medals in the International Mathematical Olympiad or from among the twenty or thirty selected students trained at the Homi Bhabha Centre for Science Education before the Olympiad team is selected), then after 40 years, in the steady state and after allowing for attrition, not more than 100 mathematicians (of the highest calibre) will be supported at a total cost of perhaps about Rs 20 crore (at today's prices). This amount is not to be read as additional cost; the cost that the Government will have anyway incurred in positioning mathematicians in their required slots would, by the new strategy suggested, have been used to induct and retain outstanding individuals.

I am optimistic about the future of R&D in India, provided necessary policy decisions and corrective actions are taken quickly. In a lecture at one of the Nobel Conferences, Glenn T. Seaborg, the discoverer of the element plutonium, quoted Edwin Land, the discoverer of the polaroid camera, who said: 'Optimism is a moral duty of Scientists and Engineers'. This is a general advice, but my optimism is also based on the quality of our young people.

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Academia–industry symbiosis: The new norm of science in socialist China

V. P. Kharbanda

With globalization and international competition, university–industry symbiosis has gained importance, particularly in China. Since the initiation of reforms of the science and technology system, it has tried to re-establish its higher education system and the research base in terms of institutional infrastructure and manpower. One of the significant moves has been to link its R&D institutions as well as higher education system to meet its economic and social needs. Industry and the academia are collaborating in more diverse ways for technological innovations in an ideological environment, which was, in the recent past, definitely adverse to private entrepreneurship and profit motives. However, it still lacks the capacity to translate indigenous innovations in terms of economic gains on a scale to compete in the globalized world. Industry mainly depends on import of technologies for its survival. R&D capabilities of the firms need to be strengthened to fully exploit the indigenous knowledge base. In this scenario, the author surveys the efforts made by the Chinese to overcome the problem of linking the knowledge base with industry and proposes some measures which could be useful for both India and China, to face the onslaught of multinational giants in these countries.

DURING the recent years, the emergence of entrepreneurial science and the resulting university–industry symbiosis has proved to be of immense significance for achieving international technological competitiveness in the developed countries[1]. One explanation for the emergence of entrepreneurial science is that academic scientists, such as the founders of biotechnology firms in the late 1970s and early 1980s suddenly awakened to the financial opportunities emanating from their research. Implicit in this explanation is the notion that there were recent scientific advances in molecular biology, polymers, material sciences and information technologies that could be quickly developed as a source of profit. It may be seen that this cognitive condition exists only in a small number of research fields and scientific disciplines. But recent developments suggest that such a cognitive shape appears in more and more scientific fields. For example, linguistics, for a long time a purely curiosity-oriented basic research field, suddenly became part of the emerging trans-disciplinary area of cognitive sciences which have strong links to computer and software industry[2]. Thus, the emergence of new high technology knowledge-intensive areas, especially micro-electronics, computer and information processing, biotechnology, new materials, etc. has accentuated the linkages between knowledge-generating institutions and the industry. This has also led to legitimization of science as a source of new high technologies. Industry harvests the potentials of fundamental as well as applied research pursued in universities. The

V. P. Kharbanda is at National Institute of Science Technology and Development Studies, Dr K. S. Krishnan Marg, New Delhi 110 012, India.