Directed basic research*

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India can become a global innovation leader provided we have 'technology foresight' to make the right technology choices, provided we introduce 'coherent synergy' in our science and technology-related activities and provided we establish an effective 'innovation ecosystem'. In this context, 'directed basic research' has an important role.

In its execution and in the requirement of no other deliverables than knowledge generation, directed basic research is no different from conventional (self-directed) basic research. The selected areas are determined in a national perspective. Directed basic research may be in an area where knowledge generation would benefit Indian society in the long term, or it may be in an area where the results of the research would benefit Indian industry or our strategic interests in the long term.

Keywords: Academia–industry interaction, directed basic research, technology foresight.

BASIC research, a cultural necessity in any civilized society and which also lays the foundation for sustainable economic growth, needs substantially increased funding. Support for self-directed research, by the highest intellects on fundamental problems of their choice, is essential. We must also selectively promote some technology areas through 'directed basic research'. These areas, selected in a national perspective, relate to the needs of society in the long term and of Indian Industry or strategic interests in the long term.

Every effort in science and technology (S&T) requires synergy among the concerned parties, and every such synergetic effort gives India a momentum for development. But there should also be coherence among the various (synergetic) efforts. This is what I call 'coherent synergy' and this is needed for fast economic development of the country.

Technology is power

The modern futurologist, Alvin Toffler had said many years ago: 'Yesterday Violence was power, today Wealth is power and tomorrow Knowledge will be power'. What is the common thread in all this – technology! So I paraphrase Toffler to say: 'Technology is power'. And this is true today more than at any time in history, and will continue to be so in the future. Technology domination is sought both by companies and by countries, in fields as diverse as human genomics and strategic weapon systems, through the instruments of Intellectual Property Rights and Technology Control Regimes. Therefore, India must become self-reliant but, as I have been saying for many years now, that self-reliance should no longer be interpreted as self-sufficiency but as 'immunity against technology denial'.

In today's world, self-reliance does not mean avoidance of international scientific and technological cooperation. In fact, the latter is a must and today's India must take and must give in equal measure in international cooperation. That is, India must go for international cooperation, including in 'mega-science' projects, on an 'equal partner' basis. This is also true for nuclear technology, where India needs the world in the short term, but there is no doubt that the world will need India in the long term[1].

Technology foresight

Technology foresight involves forecasting of possible futures, taking into account existent as well as emerging technologies, with the objective of achieving the maximum economic, social and security benefits. Technology foresight analysis has to be in a national perspective. If you ask questions in this context, the answer may sometimes be different from India and from, say, the United States of America. An example of this is fast breeder reactors. It is important for India to reprocess the spent fuel and close the nuclear fuel cycle, because we have limited uranium reserves and the world's largest thorium reserves. USA, with easy access to the world's relatively cheap uranium,

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may put away the spent fuel as 'waste' for decades. But we must remember that plutonium, with its half-life of 24,000 years, is not running away anywhere. In fact, the later you reprocess, the easier it becomes because other shorter-lived radioactivities would have died down significantly. It is not surprising, therefore, that four of the six advanced reactor systems proposed under Gen. IV by the consortium led by USA would require reprocessing of spent fuel.

India's choice of fast breeder technology as part of the closed nuclear fuel cycle strategy, illustrates how technology foresight analysis helps in the selection of critical technologies for development at any point of time. In a broader sense, what are the critical technologies for India today? India is a large country and its technology requirements also correspondingly span a wide range, from nuclear to rural. It has to continue to develop strategic technologies – nuclear, space and defence-related. Technologies related to energy security, food and nutritional security, health and water security, environmental security, advanced manufacturing and processing, advanced materials, etc. are all important for us. So are the so-called knowledge-based technologies (information technology, particularly hardware; nanotechnology, particularly nanoelectronics; biotechnology, and convergence of these technologies like nano-biotechnology for drug delivery). Among all these, I place rural development-related technologies also at high priority.

Success in the development of most of these critical technologies would be predicated on tackling basic research problems underlying these technologies. And much of this basic research would need to be directed basic research. The support for basic research in nuclear and related sciences by the Bhabha Atomic Research Centre, along with nuclear technology development, is an excellent example.

The three-stage nuclear power programme is the fulcrum of our efforts in nuclear technology. We are now one of the leaders in the world in Pressurized Heavy Water Reactor (PHWR) technology. We have self-reliance in the entire fuel cycle in this technology. This is the first stage. The second stage involves reprocessing the spent fuel from the PHWRs and using the resultant plutonium in fast breeder reactors. A test reactor has operated successfully for more than two decades and the first 500 MWe prototype fast breeder reactor is under construction in Kalpakkam. By closing the fuel cycle with plutonium, we can extract 50 times more power from our limited resources of uranium. For using our vast reserves of thorium, we would then enter the third stage of our nuclear programme. Thorium-232, used as blanket in the fast reactors, gets converted to uranium-233, which is an excellent nuclear fuel. By going into the thorium–uranium-233 cycle which, of course, would require an enormous amount of research and development (R&D), we can effectively produce 600 times more power starting from a given resource of uranium. That is why it is so important for India to close the nuclear fuel cycle with thorium. Any emerging international cooperation in the nuclear field would lead to additionalities to our own vigorously pursued three-stage programme.

Rural technology delivery

In spite of a great deal of rural development-related technology efforts, their impact, particularly in the non-farm sector, has not been significant. A variety of initiatives are now on to correct this deficiency. One of them is Rural Technology Action Group (RuTAG) started by my Office. The RuTAG initiative is based on the realization that active scientists are not the best people for grassroots technological intervention in rural India. This is because they are busy in their own areas of R&D. However, if some voluntary organization or a government agency has recognized a problem in a rural area and implemented a technological solution up to a point, the higher-level R&D institutions and universities can carry it further. Here is where my Office can help to create the required synergy.

We have made beginnings in Uttarakhand and Tamil Nadu and are making a start in the NE region. Some of the projects taken up at Uttarakhand through HESCO are upgradation of water mills with assistance from IIT Delhi, improved packaging and food processing technology with help from CFTRI Mysore, increased water recharge technology introduction through BARC using the isotope hydrology technique, low-cost solar drier through a design developed by BARC, etc. In Tamil Nadu, projects have been taken up in the areas of natural dyes (conversion from liquid to powder), improved and energy-efficient manufacturing process for ayurvedic medicines, etc. Institutions such as IIT Madras, CLRI, Anna University and NIOT are providing technology as well as R&D support. The Rutag Centres for these regions are located in ONGC Dehradun, IIT Madras and IIT Guwahati.

Much of rural technology delivery can take place on the basis of known science, what Gerhard Sonnert[2] calls 'Baconian science'. However, we also need what he calls 'Jeffersonian science' – securing a social need through new knowledge – for example, rural development. This is what I call 'directed basic research'.

Academia–industry interaction

Reverting to hi-tech industry, we have success stories in atomic energy, space, etc. – the outcomes of successful interactions between academia and industry. For convenience, I am using the term 'academia' to include both the university system and the national laboratory system. However, the driving force for these interactions in the fields of atomic energy and space came from the mission-oriented agencies. Can we have a similarly strong academia–industry interaction with the driving force originating in the industry? I think that the mindset problem in scientists and industry leaders, which has prevented this from happening in a significant measure in the past, is changing in the current liberalized environment. Technology transfer from abroad is becoming more and more difficult because foreign companies can set up shop here and are, therefore, less willing to share technologies. Moreover, Indian companies are becoming more and more globally competitive. If industry begins to interact actively with academia, it can also play a greater role in guiding academic activities in the direction of industry interests, be it human resource development, R&D prioritization, or the choice of areas of international cooperation.

At the end of several academia–industry interaction meetings in 2002 in my Office, in which distinguished representatives from both academic institutions and industry took part, we came up with a series of recommendations. One of them, which can seed 'directed' basic research is the following. Very often people with degrees in engineering do not go in for research and technology development, even though they may have a talent for it, but opt for jobs in IT, management, or just go abroad. Now, if the industry were to send some fresh employees (from among those they recruit during placement interviews in academic institutions) – the most talented among them – to do research with professors whom the industry respects and in institutions that they respect, and pay them company salaries, then there would be greater scope for industry-oriented research. The student should be no different from any other student of the professor and his research should not be limited to problem-solving for the company, which is too restrictive. Although the employee-student might not be addressing the company's problems consciously, subconsciously the company's products would manifest in his (or her) thoughts and actions in all professional interactions. Over a period of 4–5 years, he or she could evolve into someone very useful for the company's product or process development. J. J. Irani, who was actively involved with us in developing this model of interaction, told me recently, that this is beginning to happen in the Tata companies and also some others.

The automotive sector

Arising also from the discussions during the academia–industry interaction meetings I referred to earlier, a core group for R&D in the automotive sector, appropriately called CAR, was formed by my Office in April 2003. Though it is called CAR, this group deals with all vehicles from two-wheelers to heavy vehicles. CAR is mandated to identifying frontier technologies, so as to promote development of vibrant, world-class automotive systems, sub-systems and parts industries. The group has drawn up a technology road-map for the Indian automotive sector and its recommended programme includes advanced materials and manufacturing, alternate propulsion and automotive infotronics, every one of which involves basic research directed eventually to benefit the automotive sector. Projects in these areas are currently funded for pre-competitive applied research jointly by the Department of Heavy Industries, the Department of Science and Technology (through TIFAC) and my Office. I think this should be expanded to include directed basic research in some areas. This initiative has had significant success. Following the same model, my Office has set up an R&D Advisory Group for the machine tool industry and is planning to set up one for the electronic hardware industry.

Innovation ecosystem

A strong and vibrant innovation ecosystem requires an education system which nurtures creativity, an R&D culture and value system which supports both basic research and applied research and technology development, an industry culture which is keen to absorb academic inputs, a bureaucracy which is supportive, a policy framework which encourages young people to enter into scientific careers, and an ability to scan scientific developments in the world and to use technology foresight to select critical technologies in a national perspective.

A part of the innovation ecosystem is the courage to take risks on the part of the scientist and support of risk-taking by the S&T system. The greater the innovation, higher is the risk in converting it into a marketable product or process. Armbrecht[3] has said that 'the Advanced Technology Programme of USA provides a unique source of early stage support of emerging technologies, those still at a stage in their evolution too risky for any but angel investors'. India must initiate a similar programme. He also says that (South) Korea, while increasing R&D expenditure, is focusing on areas of its strength, viz. telecommunications, electronics, computers and medi-optical equipment – on ten next-generation technologies in these areas. The buzzwords in this context, I think, are 'risk-taking' and 'focusing'.

Patterns and priorities in Indian R&D

An important factor which influences the pursuit of R&D in India is what I have called many years back 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. I have classified[4] the types of R&D work done in India today into several categories. What I then considered important were: basic research; mission-oriented applied research and technology development; country-specific applied research, and industry-oriented research. Now I consider directed basic research as equally important.

My Office had a meeting in December 2002 with a group of scientists to discuss the issue of measures of progress[5] of S&T in India. The group observed that, while a count of publications is a good measure of the progress of basic research in a country, it does not capture correctly the progress of the S&T system of the country, especially for the mission-oriented agencies, for industry-related applied research, for country-specific applied research and for application of S&T for rural development and societal needs. My Office has, therefore, sponsored projects to develop the necessary measures in these various areas.

Directed basic research and the frontiers of science

India is too big a country to absent itself from any field of S&T. But how much it invests in any field at any point of time is a 'matter of wisdom' (quoting Frederick Seitz[6]). Current 'exciting' areas of basic research are often, though not always, 'directed' by the interests of the industries in the developed countries or their strategic interests. Examples are high-temperature superconductivity a couple of decades ago and nanotechnology now. This happens because their scientific research is at the frontiers of science and their industry, active at the cutting edge of technology, absorbs quickly the results of applied basic research based on current scientific knowledge. When a new phenomenon is discovered like high-temperature superconductivity or novel carbon nanostructures, USA and other already developed countries see the possible potential for their industries and direct their basic research to these areas. High impact factor journals welcome publication of the results of such research. What is directed basic research for the developed countries then inevitably becomes a frontier area of basic research for us, if we want to publish in front-line journals. We must be in these areas because usually they also involve excellent science and perhaps also help Indian technology in the longer term. What we should guard against is to prevent such research from becoming 'parasitic'[4] (excessive collaboration with developed countries, feeding exclusively into the latter's technology system; excessive value given to recognition and accolades from them), because it may distort our own national priorities.

Even Bell Labs has changed its paradigm for research in recent years. The *Wall Street Journal* of 21 August 2006, says 'Lucent Technologies Inc.'s Bell Labs, the birthplace of the transistor and the laser, has… set more of its scientific stars to work on breakthrough technologies that could quickly turn into businesses. …Steven Chu, who won a Nobel in Physics… says: "working on applied things doesn't destroy a kernel of genius… it focuses the mind"'. India should do this today in nanotechnology, using technology foresight analysis to make the right technology choices in this field. My own choices are nanoelectronics and nano-biotechnology for drug delivery.

We should thus select areas of directed basic research in an Indian perspective. The approach could be from the side of societal interest. Examples are basic sciences behind Ayurveda, health-related (related to diseases endemic to India) macromolecular crystallography, megaprostheses implants for cancer-affected patients, etc. The approach could be from the side of industry or strategic interests. Examples are nanoelectronics, cyber security and automotive infotronics.

The culture gap that exists between the practitioners of basic research on the one hand and applied research and product development on the other (this gap also exists, though to a lesser extent, even in already developed countries), could be closed through directed basic research and pre-competitive applied research (see Figure 1). In its execution, and in the requirement of no other deliverables than knowledge generation, directed basic research is no different from self-directed basic research. So the university academics should be comfortable with this kind of research. From a national perspective, scientists carrying out directed basic research in any area would find it easier to interact with the related industry or related strategic mission or to participate in related societal development programmes.

The Department of Atomic Energy, Govt of India has been successful in directing basic research to areas of relevance to their mandate and has benefitted greatly from it.

Though linkages among the various kinds of R&D efforts are indicated, the borders between them are fuzzy, particularly between directed basic research and pre-competitive applied research. The difference between self-directed basic research and directed basic research may often be only a matter of problem choice in a proximate field of the scientist's own interest area.

The need for 'coherent synergy'

'Coherent synergy' is a new phrase I have defined in the S&T context. The S&T system, to contribute maximally to national development, requires a variety of efforts –

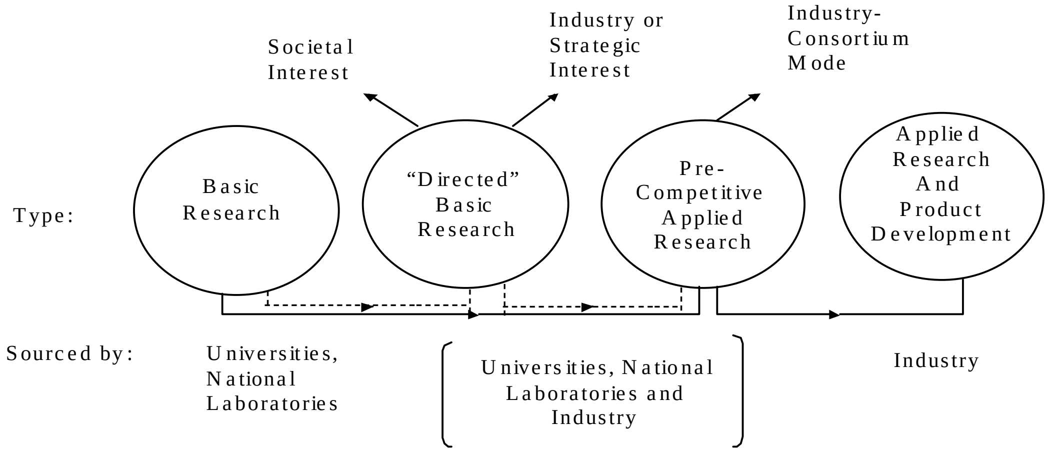

Figure 1. Linkages among needed research and development efforts.

human resource development, R&D with prioritization, academia–industry interaction, international collaboration, etc. Every S&T effort requires synergy among the concerned parties and every such synergetic effort gives a momentum for development. And momentum is a vector. All the vectors must point in the same direction for rapid development of the country. This requires space-time synchronization and phase relationship among the efforts. This is coherence. That is, synergy in every effort and coherence among all the efforts! In R&D (industrial) globalization, this implies coherence between the motivation of the transnational corporates and national technology needs[9].

Conclusion

The focus of this article has been on directed basic research, and on elucidating its significance in relation to critical technologies in a national perspective. I must clarify that this is in addition to self-directed basic research. Sustainable economic development at all times requires extensive and high-calibre basic research of both types. While directed basic research should be encouraged, self-directed basic research should also receive substantially increased support. The study of the ultimate structure of matter or of the origin of the universe, for example, is a cultural necessity. You also do not ask a Raman or a Ramanujan why he is doing what he is doing!

India can become a global innovation leader provided we have 'technology foresight' to make the right technology choices, provided we introduce coherent synergy in our S&T-related activities and provided we establish an effective innovation ecosystem. We must also selectively promote technology areas through directed basic research.

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