



## **Accelerating research and education for the growth of life sciences & biotechnology**

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### **Abstract**

Among the developing countries, India has recognised the importance of biotechnology. Policies are being framed by the Government of India for progressive growth in education, research and employment and to bring self-sufficiency to meet the ever-growing need of the biotech industry for skilled manpower. However, there are still impediments in the improvement of quality education due to inadequate infrastructure in most of higher learning educational and research institute in India. In spite of this, significant developments in education have resulted in development of opportunities for specialized jobs through skilled based education. This has accelerated the progress in the nascent field of biotechnology. The developments could lead to the establishment of large number of educational hubs offering graduate, post-graduate and doctoral education in various disciplines of life sciences and biotechnology. Human Resource Department (HRD) and other scientific ministries in India are supporting programmes and schemes for the promotion of science based specialized education to shape up the younger minds. The Department of Biotechnology (DBT), Govt. of India is striving hard to promote research and education in life sciences and biotechnology in India. There has been a transformative change in capacity building and leadership development in research management through strategic approach. This article traces the evolution of biotech education in India focusing on diversifying issues concerning its growth and expansion, promotion of various schemes and programmes by DBT and associated nodal agencies. These aspects are well highlighted in the paper.

**Keywords:** research, education, skill development, schemes, mentorship, biotechnology, universities, post-doctoral, GM crops

### **Introduction**

India's efforts in education and R&D are rated at par with the world class research. The infrastructure has been largely expanded in science based educational and research institutes with increased budgetary support. This has resulted to improve the knowledge levels of youth at school and college levels in their professional career and self-employment. Improved standards of education and technological infrastructure have created avenues for research and promotion of education. The establishment of state-of-art research facilities is a way forward to encourage science graduates especially the biotechnologists in life sciences to take up research as a profession. Also the establishment of Centres of Excellence for promotion of scientific research caters with research incubators at schools and colleges, supports the vibrant biotechnology sector to carry out discovery-oriented research by the students. In India, until the 1960s, biological research was largely directed toward pragmatic applications in agriculture, nutrition, and public health. The modern biological research came into being much later. As a step one, IISc, Bangalore established a laboratory with groups of scientist working a fermentation, pharmacology, and silkworm biology. The first truly modern "molecular biology research unit" was established in 1962 as a branch of the Tata Institute of Fundamental Research (TIFR) in Mumbai, an institute originally devoted solely to physics and mathematics. In the late 80's i.e. in 1986, the National Institute of Immunology (NII), whose initial goal was to develop vaccines broadened its scope several years later and is now conducting a wide range of basic biological research. The Center for Biochemical Technology, which was initially as a producer of biochemical reagents in India in 1977 was renamed after 'The Institute of Genomics and Integrative Biology' in 2002 with the required infrastructure

and facilities for conducting research in basic sciences. The National Facility for Animal Tissue and Cell Culture was established in 1988 as a repository facility and distribution center for cell lines. In 1995 it was up-graded as a full-fledged establishment known as The National Center for Cell Science (NCCS) in 1995. India is investing heavily in the infrastructure development for promoting research facilities in life sciences and biotechnology and also upgrading to bring them on par with similar facilities available in the USA and Europe.

### **Science and Technology Education in India**

In India, there has been rapid advancements in S&T, strategically important for generating a critical mass of highly educated and skilled manpower at secondary and tertiary level. This was placed on national agenda by the Union Government of India through its policy frame work for providing high quality education in schools and institution of higher education (Shukla and Kakar, 2006) [28]. The union government has formulated two national education policies, one in 1968 and the other in 1986 with further modification in 1992. In 1968, the education policy laid stress on quality improvement with equitable expansion of educational facilities and infrastructure and also focussed on girl's education. In 1986, the policy provided a comprehensive framework for development of education with a Plan of Action (PoA) by assigning specific responsibilities for organising, implementing and financing the implementation schedule. Currently, there are more than 350 Universities existing in India, a spectacular rise since independence. Most of them are universities funded by State universities. In addition there are few central and private universities. The Universities are primarily dedicated to Master's degree, Ph.D and other training programmes. The Government of India is

fulfilling the recommendations of setting up of a National Commission/Council for higher education and research by giving more autonomy to universities and institutions of higher learning and research.

The great scientific and educational contributions by Indian Institute of Technology (IIT), Tata Institute of Fundamental Research (TIFR) and Indian Institute of Science (IISc) during the past 50 years have been recognised globally. India has acquired the status of a knowledge economy with a huge infrastructural base to support the education system. These are the top global rated institutions with well-equipped infrastructural facilities, providing better avenues to scientists and academicians for research promotion. However, these are very few among the examples which can be cited.

India's S&T capability is growing very fast and India is rated the third-largest scientific and technical manpower in the world. There are more than 162 universities awarding over 4,000 doctorates degrees and 35,000 post graduate degrees annually. In the revamping process of education both the disciplines of biology and science education have undergone sea change. At undergraduate level in science, technology, engineering, and mathematics (STEM) education, new approaches and new technologies are also emerging based on evolving theories of learning (Donovan *et al.*, 1999 NRC, 1999, NRC, 2003) [9, 21, 22]. The developments in the nature of institutions of higher learning have changed the persuasion for higher education who enter for careers other than those related to science and with the growing realization to educate the students well with the wealth of professions available in science education (Alberts, 2008) [1].

The Govt. of India has realised the need to further improve the competitive ability of the educated youth especially in technology-based science subjects. There exists three principal levels of qualification within the higher education system, the bachelor/undergraduate level, the masters/postgraduate level, and the doctoral/pre-doctoral level. As one goes higher up the ladder, the course becomes more challenging and specialized. The enrolment in higher education in India is steadily growing at a rate of 6.1% but this reported is quite low when compared with the booming economy of the country. The students in India generally do not opt for higher studies. It is only 2.5% of the population enrolls in post-graduation studies, while only 0.0283% go for higher education at the doctorate-level. Further, it is only 20.45% of students who enrol in the faculty of science and the major chunk (45.13%) opts for the arts stream (Kumar and Kumar, 2009) [16]. The Govt. of India has constituted the National Knowledge Commission (NKC) with a mandate to focus on the provision of easy access to knowledge, the creation and preservation of knowledge systems, the dissemination of knowledge and the creation of better knowledge services. NKC is focusing on expansion, excellence and inclusion in the education system for economic growth of the country by generating new frontiers in educational avenues. India's competitive edge highlights the International market, potential for the investments in the educational sector and global business with collaborative International partners for actionable implementation of educational programme reviewed well (Gopika Kannan, 2005) [11]. As per the census of 2001, the literacy rate of India is 64.84%.

India still has to harness its knowledge potential since a large pool of youth is available in the Country. According to the

population facts of UN, population division, there were 1.2 billion youth aged 15-24 years globally in 2015 and by 2030, the number of youth are projected to be grown by 7% to nearly 1.3 billion. Youth can be a positive force for development provided they have given opportunities of knowledge gain through educational and skills improvement to contribute in a productive economy. There are great challenges facing many countries today due to inadequate human capital investment and high unemployment rates among youth in Asian Countries including in India (PROFACTS, 2015) [26]. Vibrant economic growth could be possible by giving importance to the youth education as an integral part of the national agenda. MHRD, the key nodal agency for education which is in charge of school-level education and higher level education in all the spheres of Science & Technology, culture, art and literacy and is also responsible for maintaining standards of education by providing grants to eligible universities and colleges (Anon, 2015) [3].

### **Educational- Research Policies**

The Scientific Policy Resolution (1958), the Technology Policy Statement (1983), and the Science and Technology Policy (2003) of the Government of India are the indications of the continued political commitment to support S&T and represent a vision for its development. NSTP-2003 of the Government and the Vision Statement on Biotechnology by DBT provide a framework and give strategic direction to different sectors to accelerate the pace of development of biotechnology in India over the next ten years. Among the developing countries, India is one of the countries which recognised the importance of biotechnology as a tool to advance the growth of the agricultural, health and environment sectors as early as the 1980s (Chaturvedi, 2002) [7]. Since then, the Indian government has been working on developing its biotechnology sector, with policies focused on numerous technology promotion programmes that have created infrastructure along with evolving organisational structures which have contributed to the progressive growth of biotechnology (Mehra and Joshi, 2010) [18]. The government policies that promote the development of biotechnology have encouraged the participation of industry and academia, which has increased the sustainable growth. Further the need was felt to address the development of skilled manpower for the successful implementation of mission based projects in S&T and biotechnology (Bhanu Pratap Singh, 2014) [6]. It is estimated that between 35% and 40% of government expenditure is spent on elementary education, another quarter on secondary education and very less goes to university and higher education (Shukla, 2005) [29]. For research promotion in India, fund comes from various sources including the central government and the state governments. The spent grant is around 4% of gross domestic product (GDP) on education each year. The research and technology oriented streams are information technology, nanotechnology and biotechnology. The prominent new technological areas to be explored in the field of agriculture, human and animal health and environment protection to develop new value added products, processes and techniques/tools.

India has witnessed a spectacular growth rate of more than 30% in biotech sector during the past five years. The bio-pharma segment has shown the highest growth rate (67%) (Natesh and Bhan, 2009) [20]. Considering the size of the

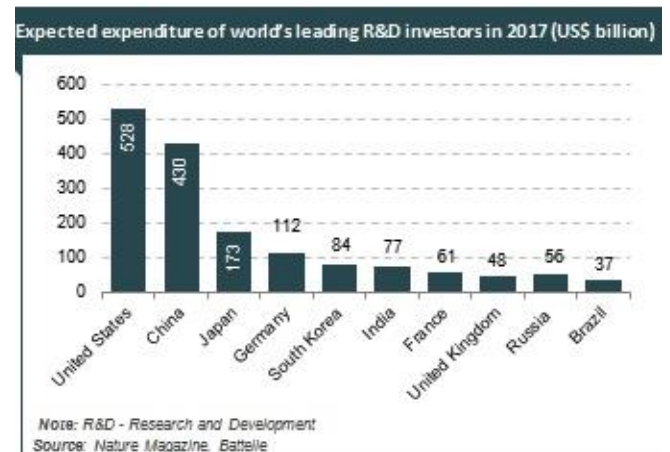
entire Indian biotech industry, the growth can be effectively managed by pooling resources like research facilities, technological competence, manpower requirements, risk-taking ability, etc. Technological competence in terms of human resources and research facilities coexisting with the educational infrastructure underlines the need for skilled manpower in the sector of life sciences and biotechnology. During the last 25 years, the transition occurring in biotechnology has invariably experienced different degrees of transformation in terms of policy, education structure, infrastructure, human resources, etc. It has changed the character of the education structure from an exclusively formal and public one to extremely area-specific and super-specialised requirements. The last decade basically belonged to biotechnology as areas like health, industry, agriculture, environment and animal husbandry had some or the other biotechnological applications. The pharmaceutical industry is the key to health-care products, meeting almost 95% of the country's pharmaceutical needs. The industry has been the largest user of this technology for developing vaccines, medicines and diagnostics, clinical and contract research, etc. Similarly, with the approval of the Bt gene being spliced into cotton seeds, genetically modified crops are on the verge of being marketed. This has resulted in the eruption of numerous seed firms and tissue culture laboratories. Further, the biotech industry is largely based on manufacturing and services. This has opened increasing markets for new products as a sunrise industry sector requiring a huge mass of skilled labour. The policy driven initiatives are shaping the future of life science and biotechnology. The students coming out after secondary, higher secondary and undergraduate educations are not adequately engaged in research and development activities. This is a critical need to be addressed through quality improvement in academic institutions and with focus on skill development. The participation of the academic institutions and industries through Public Private Partnership can further harness the education sector better and create a platform for research to help in teaching and practical training of students. In India, agriculture and pharmaceutical sectors are more visible than industrial and environmental sectors by addressing innovation and product development issues beyond the public and private sector scientists and industry. To prepare the biotech students in higher education Biotechnology Finishing Schools are run by Union States of India and managed by private partners Association of Biotechnology Led Enterprises (ABLE), Bangalore. However, these schools need to be well recognized under the formal system such course curriculum of the students with credibility. Institute of Bioinformatics and Applied Biotechnology, Bangalore, offers post degree diploma courses and training in bioinformatics and biotechnology, as well as in entrepreneurship. The opportunities IBAB is also providing hands on practical training, after biotechnology degree courses at other institutions but the efforts are very limited (Kameswara Rao, 2013) [14].

### Investments in R&D Sector and Biotechnology

There has been a significant increase in the Government funding for science and technology. There are more than 22 central funding agencies responsible for sanctioning grants for science and technology research in the country for extra mural sponsored projects. Its aim is to develop research capability, infrastructure and excellence in research and education (Lalit Mohan, 2016) [7]. India is working hard to

improvement of the quality of science by injecting more funds and creation of new scientific institutions to fill the gaps in research and education. India's investment in R&D with a budgetary provision of about US\$ 66.5 billion for supporting research ramps it at 6<sup>th</sup> position in the world (Farrel and Beinhocker, 2007) [10]. The funds allocated for higher education are not sufficient to pursue quality research. The central government allocates funds for biotechnology predominantly through the following ministry departments: MHRD, DBT, DST, ICAR and ICMR. Biotechnology is the future of the country and the private sector is the driving force of biotechnology supporting industrial R&D and production capabilities which in turn greatly influences on human resource development. India's investment in R&D sector is expected to rise from 0.9 per cent of Gross Domestic Product (GDP) in 2016 to reach 2.4 per cent of GDP in 2034. India's share in global R&D spending rose to 3.67 per cent in 2016 compared to 3.53 per cent in 2015 and is further expected to rise to 3.75% in 2017 as per projections even though the Indian investments into basic research did not keep pace with the requirements during the 1990s. However, several intervention plans have been launched since 2000 to promote basic research in the country. Policy measures in S&T and its effective implementation could attracts private sector funds into research and development are being made by the Government of India. The Indian government has introduced various start-up intellectual property protection schemes to ease patent filing to promote awareness and adoption of IP rights for protection and commercialising of IPRs. These schemes provide access to high-quality Intellectual Property services and resources. Institutions under the Government of India are further extensively promoting research parks technology business incubators (TBIs) and (RPs) which would promote the innovative ideas till they become commercial ventures. This may take a lead in basic and applied research in India and is likely to boost up better than past and at present.

India is one of the leading nations in the world in terms of Science & Technology and has large pool of scientists and engineers. It is one of the top-ranking countries in the field of basic research and ranks 12<sup>th</sup> in terms of the number of patents filed with 24,898 patents filed in 2017. Globally, India ranks 9<sup>th</sup> in terms of the number of scientific publications produced.



Source: Adopted from Nature Magazine

Fig 1

The Department of Biotechnology is the scientific

department of the Govt. of India in the Ministry of Science & Technology, promoting biotech education in the country. It interacts with stakeholders, students, faculty, experts, academic institutions, research institutes and the biotech industry. Since the establishment of DBT in 1986, the major focus was on integrated human resource development to cater to the needs of R&D, teaching and biotech industry promotion. It plays a pivotal role in student development by promoting the quality biotech education. The higher secondary students are being nurtured with excellence at undergraduate and post graduate level by providing practical training and minor research exposures. The PG graduates in biotechnology are given training with stipend in industries. Fellowships for doctoral and post-doctoral research with integrated teaching approach are provided for pursuing basic and applied research in biotechnology and integrated sciences. Opportunities are created for training research scientists by providing a forum for interaction in the form of seminars/symposia, short term training courses in advanced techniques and associateships for training in leading national and overseas laboratories (Sundee Sarin, *et al*, 2017) [30].

### **Education Programme in Biotechnology**

#### **Post-graduate Programme in Biotechnology**

In the initial phase, DBT had given emphasis to a HRD programme for intensive teaching and training of young students, the training of scientists and technicians at various levels, from research associateships to midcareer scientists, and exposing visiting scientists from advanced countries to newly developed techniques used in biotechnology (Gupta *et al*, 2009) [12].

The DBT in 1985-86 provided initiatives to start courses in Biotechnology in six universities, and these have, in just two and a half decades, expanded to over 72 universities today. The Biotech Industrial Training Program (BITP) provides industrial exposure to biotechnology post-graduates. The Young Entrepreneurs Scheme (YES) encourages students towards entrepreneurship. Other programmes include BEST (Biotechnology Entrepreneurship Student Teams), Junior Research Fellowships (JRF) and Senior Research Fellowships (SRF). The selection for the doctoral fellowship to pursue a JRF or SRF for a PhD is through the Biotechnology Eligibility Test (BET) conducted in India. The National Entrance Test conducted by both the CSIR and the UGC help to select candidates at national level to provide fellowship to carry out research in Biotechnology. A postdoctoral fellowship is being supported through Indian Institute of Sciences, Bangalore, for selection for Post-Doctoral Fellow (DBT-PDF) programme in India. For the faculty, there are short-term training courses (2-3 weeks); Biotechnology Overseas Associateship programme; visiting scientists from abroad programme; distinguished biotechnology research professorship; National Energy Bioscience chair; Energy Bioscience Overseas Fellowship; Ramalingaswami fellowship; Wellcome Trust fellowships by the DBT; National Fund for Basic, Strategic and Frontier Application Research in Agriculture (NFBSFARA); and the National Agricultural Innovation Project (NAIP) by ICAR are available to enrich the knowledge in the field of biotechnology. The state governments in India have also taken up the initiative for biotech development. There has been close interaction with the state governments, particularly through state S&T councils in terms of developing biotechnology application projects,

demonstrating proven technologies and providing training in human resources in states and Union Territories. Viable projects have been evolved with various states for setting up institutes providing high-end biotechnology education and research and with the commitment to the investments in land and buildings by the state.

The revolution in modern biotechnology education has made India to introduce formal education in biotechnology by creating good infrastructure and the manpower to boost the India bio-economy. The DBT has launched several programs to encourage entrepreneurial activities that to support industry with creation of scientific and technical competence particularly the entrepreneurship development for industrial expansion. In India, the biotechnology education was reviewed in detail and discussed with diverse issues in biotechnology education (Kameswara Rao, 2009) [13]. The PG teaching programme in biotechnology was initiated by the DBT as early as 1985-86 in India. Based on the need for specialised manpower and regional aspirations, the teaching programmes have been expanded to over 70 universities covering different specialisations such as general, agricultural, medical, pharma, environmental, marine, industrial, bio-resource, veterinary, food and bioprocess engineering. The implementation of the scheme during the last three decades created the best model for producing quality students, teachers and researchers. Faculty is creating a nucleus for research work with industry and R&D organizations. The M.Sc./M. Tech. graduates in biotechnology and bioinformatics meet the need for quality teaching by sharing faculty and infrastructure through partnership with UGC. In-house dissertation has been made mandatory, for which a thesis grant is provided to students to ensure good quality research. The placement of students is tracked with the established placement cells of the respective universities to help students in finding placements and by organising campus interviews. Although efforts have been to improve biotechnology education to provide adequate employment opportunities to the PG and Ph.D. students, the students have not been well preferred to take placements in the industrial establishments.

Despite the fact that the biotechnology sector is a booming sector, students consider R&D as the only option and are not willing to consider even better-paying job offers in production/manufacturing, quality control and analysis, marketing, consultancy, intellectual property rights and regulatory affairs, etc. The major employability is the issue for these super-specialty areas which is matter of concern for which corrective measures are required to ensure optimal utilisation of the scientific knowledge (Wiig, 1999) [35]. By enhancing the employability and to bridge the skill gap between students produced by the universities and requirements of the industries, the Department initiated Biotech Industrial Training Programme in 1993-94 to provide industrial training to M.Sc./M. Tech students in biotechnology. This programme is mutually beneficial and is highly popular with students as it gives them first-hand experience of industry environment. This also meets the expectations of the students as well as provides opportunity for industries to select their prospective manpower in biotech companies. As per available data 25 to 30% students find jobs in industry and biotech companies with their area of specialization. The in-house industry training boosts the morale and develops confidence among the students. Many finishing schools have been introduced realizing the

development of soft skill training in professional life finishing school are also required for the perfection of education at schools and universities and also to address various other issues in biotechnology and life sciences education and business planning. These schools have gained popularity in offering supplementary education to the students and fulfilling the deficiencies in the academic programs and curricula. These challenges are being addressed by promoting finishing schools to bridge the gap between industry and academic curricula, by exposing students to crafted courses suitable to meet the needs of industries.

#### **Government Ministries involved in biotech sector**

S&T policy driven approach to promote biotechnology is to generate an educated mass in areas related to biotechnology through various ministries of central government, including the Ministry of Human Resources and Development (MHRD), the Ministry of Science and Technology (MST), the Ministry of Health and Family Welfare (MHFW) and the Ministry of Agriculture & Farmer's Welfare (MoA&FW). The Department of Science & Technology (DST) established in May 1971, is primarily entrusted with the responsibility of formulating S&T policies, their implementation, identification and promotion of thrust areas of research in different sectors of S&T, such as technology information, forecasting and assessment; international collaboration and the promotion of science and society programmes; and the coordination of S&T activities in the country (Phil Mjwara, 2017) <sup>[25]</sup>. The Department of Scientific and Industrial Research (DSIR) has a mandate to carry out activities related to indigenous technology promotion, development, utilisation and transfer. The primary endeavour of DSIR is to promote R&D by the industries, support a larger cross section of small and medium industrial units to develop state-of-the-art globally competitive technologies of high commercial potential, catalyse faster commercialisation of lab-scale R&D, enhance the share of technology-intensive exports in relation to overall exports, strengthen industrial consultancy and technology management capabilities and establish a user-friendly information network to facilitate scientific and industrial research in the country (Anon, 2017) <sup>[5]</sup>.

**MoA&FW:** The Indian Council of Agricultural Research (ICAR) is an autonomous organisation under the Ministry of Agriculture and Farmer's Welfare Research. As an apex body it coordinates, guides and manages research and education in agriculture in the entire country, including horticulture, fisheries and animal sciences. Another apex body under Ministry of Health and Family Welfare (MOHFW), the Indian Council of Medical Research (ICMR) is responsible for the formulation, coordination and promotion of biomedical research (S. K. Singh, 2017) <sup>[27]</sup>. The Ministry of Science & Technology has three departments. DBT is the nodal agency in the country for evolving enabling policies and for conceiving and implementing research and development (R&D) programmes in the biotechnology sector. After its establishment in 1986, the department is ensuring that applications of biotechnology occur in the broad areas of agriculture, health care, animal sciences, the environment and industry (Sundeep Sarin, *et al*, 2017) <sup>[30]</sup>. Under the HRD programme, DBT is supporting an education programme for under graduates upto post-doctoral level and also to faculty or industrial in-house training to fresh post

graduates through allocation of funds, fellowships for R&D and infrastructure development, etc. The need for an integrated biotech policy with concurrent attention to education, social mobilisation and regulation is an essential pre-requisite for the progress of the Indian biotech sector.

The Government has launched a new Scheme, "Innovation in Science Pursuit for Inspired Research" called INSPIRE. It is an initiative for attracting talent to study science through a long term programme. The Ministry of Science and Technology is implementing the scheme through the Department of Science and Technology. The program provides one million science awards for youth based on performance in the school board examination, scholarships for pursuing degree-level courses in natural sciences, doctoral level fellowships and faculty positions for post-PhD professionals, along with assured research funding over a period of five years. The scheme includes contact and summer research program with mentoring support. Special program for promotion of basic research in Biotechnology, The Department of Biotechnology aggressively promotes research and development in the frontier areas of biotechnology. Various programmes developed for school students are the innovation in science pursuit for Inspired Research (INSPIRE) programme by the DST to assist students in their early career through attraction of talent for science, scholarship for higher education and assured opportunity for research careers, Star College Scheme of DBT. The aim of this scheme is to improve hands-on-exposure and practical training of the biotechnology component in existing life science courses. However, the promotion of biotechnology depends on a qualified manpower in the form of qualified technicians. The impetus is given on the development of biology and biotechnology with creation of trained manpower by exposing the students and technicians to recent developments in the area of genetic engineering and molecular biology and biotechnology and their exploitation in industry, agriculture and medicine (Thirumalachari Ramasami *et al.*, 2009) <sup>[33]</sup>.

#### **Infrastructure in Educational System**

Educational policies in India, propel have led the growth of higher education that led to the creation of vast educational and S&T infrastructure within the government R&D institutions, universities, NGOs and industries. This provides a base for the development of new scientific and technological knowledge. For the promotion of S&T, R&D infrastructure has been created in more than 400 national laboratories, 1300 recognised in-house industrial units, several government departments, and private institutions and foundations that are engaged in scientific research and education in 358 universities in the country. India has one of the largest systems of higher education, which includes colleges, universities, institutions of national importance and autonomous institutions with the status of deemed universities. Of late, even the private sector has ventured into the education sector and opened numerous colleges all over India. With the support of DBT, the biotechnology sector of India is now industry driven. The revenue generated within the last seven years has grown nearly five times. According to the journal, Bio-spectrum (Kirti Joshi *et al*, 2013) <sup>[15]</sup>, the biotechnology industry in India notched up a growth rate of 18% during 2008-09. The biotech industry has compartmentalised into the sectors of bio-pharma, bio-services, bio-agriculture, bio-industrial and bioinformatics.

The biopharma sector accounted for the major share, followed by services and the agri-sector.

### **Shaping skill development**

In India, there is an increasing demand for skilled human capital to meet biotechnological research and develop biotechnology-oriented products. In-house R&D generates new technology and skilled persons. DBT through its Biotech Industrial Training Program (BITP) is fulfilling this need with the support of private institutions working as finishing schools in biotechnology and bioinformatics. The major share of training is offered by healthcare companies, followed by agriculture-based ones, bio-services, pharmaceuticals, etc. After intensive training the students are absorbed in maximum numbers in biotech-based companies. The biopharma sector accounts for nearly two-thirds of the industry share, followed by bio-services and bio-agriculture. The bio-agri sector, whose main product was Bt cotton (genetically modified cotton where the Bt gene is spliced into cotton seeds) marketed by more than 25 companies, has catapulted, with a 30% growth in revenues. This sector is looking forward to more products coming into the market following the approval and entry into the system of other GM crops. Biotechnology has grown in India in almost all the sectors which includes the medical field (healthcare/pharma), bioinformatics, agricultural biotechnology, bio fertilisers, bio pesticides, national bio resource development, plant biology, marine biotechnology, etc. The skill set of biotechnology is imparted through courses such as the BSc, BE, BTech, the 5-year integrated BTech/MTech) and is also at post-graduate level (Msc/ M.Tech).

Many prestigious institutes such as Indian Institutes of Technology have been offering a four-year B.Tech course in biotechnology and biochemical engineering for quite some time. DBT is supporting biotechnology programme in general biotechnology, agricultural biotechnology, medical biotechnology, marine biotechnology, bioinformatics, industrial biotechnology and pharmaceutical biotechnology. Newer areas, such as functional genomics/proteomics, cleaner technologies, gene therapy, bio-safety, molecular and human genetics, rational drug designing, upstream and downstream processing for recombinant products, IPR and patenting in biotechnology, etc. are recognized as top priority areas according to the national biotechnology development strategy published by DBT (Anon, 2015) <sup>[3]</sup>.

### **Research Excellence & Innovation**

DBT supported the establishment of Centres of Excellence, infrastructure development, creation of knowledge based centres both in basic and applied aspects. Also the state-of-art institutes like IITs, IISER are contributing to research innovation and strengthening physical infrastructure in laboratories, library, teaching aids and networking with impetus on research at the graduate and PG level. It also promotes incubation of ideas in students and creates a platform for students to become entrepreneurs. India is a signatory to GATT, and hence a sudden spurt in filing of patents as well as dispute settlement has been witnessed, resulting in immense opportunities for patent attorneys and examiners. The teaching and research in existing public and private sector universities, IITs, IISERs, NIPERs and AIIMS have shown multi fold increase in recent years and also figure high on global educational quality for research and excellence with the support of biotechnology. There has been

a continuous perusal of R&D innovation, knowledge dissemination, and solving the problems of researchers and students in need-based research-oriented issues. Skill development in teachers through faculty training programme helped improved curriculum and practical training to students with specialised infrastructure and consumables.

### **Star College Scheme in UG Science Education**

Over the last several years, it has been increasingly felt that the best brains are not joining science courses but instead opting for professional courses in engineering, medicine, management etc. Undergraduates from college learn facts from textbooks and do not understand the excitement of research and are not taught the latest scientific developments. However, the long gestation period in science courses, lack of employment opportunities, the quality of teaching in science are the deterrents factors and therefore many bright students who pursue undergraduate biology degrees are not competent enough to train students for careers in the sciences, since college biology teachers have little, experience in scientific research (Sur, 2005) <sup>[31]</sup>. DBT has conceived Star College Scheme for the holistic development of all science departments in selected undergraduate colleges by strengthening laboratories and providing infrastructure, providing opportunities for interaction with participating departments in the college and visits to nearby research institutions and industries. Support to different science departments in undergraduate colleges under Star College scheme has inculcated inter-disciplinary culture by holding joint practical, projects and workshops. Emphasis is also given to practical training and exposure to minor research to undergraduate students to inculcate interest in science. Colleges are also organising outreach activities for students and teachers from neighbouring schools and colleges in important and socially relevant scientific issues.

### **Research Promotion in Undergraduate Colleges**

For improving the educational pipeline and for attracting students to become life science researchers new educational institutions have been established in the form of the Indian Institutes of Science Education and Research (known by the acronym IISER) in Berhampur, Bhopal, Kalyani, Mohali, Pune, Thiruvananthapuram and Tirupati. The IISERs offer five-year combined bachelor's/master's programs for training in science education and research, admitting a relatively small, select class. In their first two years, students are exposed to an integrated curriculum in physics, chemistry, math, biology, history of science, and science writing, thus requiring collaborative teaching and curriculum development between faculties in different departments. The third and fourth years are devoted to specialized didactic and laboratory training, and in the fifth year a thesis has to be submitted. The faculty who join the IISERs are establishing internationally competitive research programs and will train undergraduates to perform research in their laboratories. Biology has also been introduced in the Indian Institutes of Technology. The IITs at Kanpur and Mumbai have started biotechnology departments, and several new IITs are being established, some of which are likely to have biotechnology/bioengineering departments.

### **Women in S&T Pursuit**

Women are role models for future developments in research and scientific programmes, however, their achievements are

not recognized well in all the fields including science and technology. While women undertake education at graduation, post-graduation and doctoral levels, most of them are not actively engaged in further research. Due to gender many of the well qualified women get left out of the science and technology. The perceptions of women scientists in India, regarding the work and social environment and the problems faced by them are well reported. The findings show that women academic scientists are influenced by the prevailing socio-cultural system, gender-related difficulties at work and also dual burden resulting in stress (Namrata Gupta and Arun K. Sharma, 2002) <sup>[19]</sup>. The negative attitude of women about science and technology remains active due to the influence of socio-psychological parameters. This inequality in science and technology can be reduced by proper monitoring, proper informing and creating necessary work conditions in these fields (Devananda Beura, 2017) <sup>[81]</sup>. S&T sector has shown sustained growth over the years despite great challenges facing the all-important workforce play a pro-active role in teaching and education by addressing the gender equality issue. Specific schemes for women especially in higher education are witnessing the entry of women in different science disciplines, including engineering, arts and humanities. These schemes are also involved in teaching, scientific research and extension activities from lab to field and in every sphere of S&T. Educated women are working as bio-scientist in R&D labs and pharmaceutical companies.

In order to avoid gender inequality and to address the needs, analysis was made to identify the various funding agencies that support research schemes exclusively for women. University grants commission (UGC), Department of Biotechnology (DBT), Science and Engineering research Board (SERB) Department of Health research (DHR) and Department of science and technology (DST) have launched separate schemes exclusively for women having aptitude towards research in science and technology. Therefore the number of women with doctoral and post-doctoral research experience is comparatively lower than expected (T. Angeline, 2015) <sup>[32]</sup>.

Further to have a better practical solution, the Department of Biotechnology is supporting Biotechnology Career Advancement and Re-orientation Programme for women Scientists mainly for the career development of employed/unemployed women Scientists by providing extramural research grants in the areas of Life Science and biotechnology. The scheme has also been extended to unemployed women scientists' after a career break so as to help them undertake independent R&D projects. Women participations greatly accepted in adoption of appropriate technologies and knowledge to disseminate technology in entrepreneurial parks/ women development centres to develop rural folk. The scheme also enhances the participation of Women Scientists in Biotechnology Research promotion. Creation of awareness through training and counselling programmes for women teachers are widely disseminated by S&T councils through qualified women folk. The programme is targeted towards career development of employed/unemployed women scientists in all areas of Life Science or Biotechnology (including agriculture, veterinary science and medicine). University Grant Commission is providing Post-Doctoral Fellowship to women to kindle their talented instincts to carry out the advanced studies and research in various disciplines of science. The unemployed women candidates holding Ph.D.

degree in their respective subject areas are eligible for the fellowships.

To overcome with the difficulty and address the gender issue in science promotion, the Department of Science & Technology has a supporting scheme for women scientists and technologists on similar lines. In India, this support is very pertinent for those who have breaks in their career due to social responsibilities and are interested to return to the field of science and work. The promotional schemes of Government supporting women's development to enable them to realize their full potential, get equal access for their participation in decision making of women in social, political, economic and S&T development activities of the nation.

Life sciences and biotechnology enterprises and companies, which includes businesses that use biotechnology, such as medical laboratories, IT bioinformatics, biotechnology ventures, pharmaceutical, chemical, food, agrochemical, and seed companies are finding ways to spent their earnings on promotion of research in S&T and biotechnology. They are investing in social awareness creation and train the community in farm based activities to promote new hybrids and biotech crops with a future strategy to market their produce in a better way. The research is being pursued on genetic engineering and molecular biology aspects by taking responsibility of genes and gene based products and GMO based and recombinants with their adoption to the environmental conditions and human ethics (Yoshihiro Okada, 2008) <sup>[36]</sup>. Department of Science & Technology, New Delhi through TIFAC launched a scheme KIRAN-IPR for women having Science and Engineering qualification. Women with the required qualification are trained in the area of intellectual property rights, especially in patent searches, understanding of patent specification and preparation of technology. Young women in science are encourages with scholarships to pursue scientific studies in a recognized college or university in India by providing them scholarships. The India biotech companies and the PSUs like Indian Oil Corporation Limited are awarding educational scholarships to meritorious students across the country with special encouragement to girls & the physically challenged. The dissemination of educational material addressing the gender issues in Greek computer science text book has been depicted with the role of teacher and students at the school level by portraying the teaching materials to understand how learners behave in their analysis with gender based studies for adoption of new technologies (Papadakis, 2018) <sup>[24]</sup>. In implementation of the education system, information and communication technology (ICT), being a powerful dissemination system used for skill enhancement for many end-users. ICT being a booming industry, the public, parents and students are seriously taking advantages to gain knowledge in the sector of biotechnology and bioinformatics to grab unlimited opportunities for high paying jobs and overall development from modern biotechnology research and education. The present day focus is also being on adoption of ICT technology in education sector addressing well with the gender issues. Considering immense scope for harnessing ICT to improve the quality of education, the major emphasis is given by the Ministry of Electronics and Information Technology by launching Saksham Power to train women students for acquiring industry relevant skill in IT and electronics for video conferencing and sensitizing virtual classroom learning.

### **Special Mission in Education**

The Atal Innovation Mission (AIM) is being promoted in interface with ABLE and FICCI to enhance research capability to build S&T and biotechnology through industry academia participatory approach in bio-sciences. AIM includes Self-Employment and Talent Utilization (SETU) with an endeavour to promote a culture of innovation and entrepreneurship by creating platform for promotion of world-class Innovation Hubs, Grand Challenges, Start-up businesses and other self-employment activities, particularly in technology driven areas. The mentorship creation supports and encourages inter-disciplinary education and training in ethics, communication and leadership. It also supports the establishment of high end research labs for pursuing M.Sc./ Ph.D programmes and create competence in knowledge based economy.

### **Leadership Development in Educational Institutes**

The prime focus of National Centre for School Leadership NUEPA is transforming ordinary schools into schools of excellence and eventually bringing about improvement in the entire school system through leadership development. The leading priority for NCSL therefore, is to prepare school leaders for school transformation. This would involve continuous engagement of administrators and practitioners to transform schools through collaborative effort involving stakeholders in higher education and research (NUEPA, 2014) [23].

### **Institutional Talent Building**

The talent both in-house and outside India is needed in S&T sector with mentorship support. Schemes like Visiting Advanced Joint Research Associateship (VAJRA) promoted by Department of Science & Technology with strong international connect to the R&D ecosystem of India, adjunct/visiting faculty from overseas R&D professionals including Non-resident Indians (NRI) engaging in developing high quality collaborative research in public-funded academic and research institutions of India are being implemented. The faculty is engaged in collaborative research in cutting edge areas of science and technology and also involved in technology development, start-ups, etc. The Department of Biotechnology is also supporting a visiting scientist scheme for working with Indian scientists/ faculties for 6 months in Indian R&D labs to help the scientists in life sciences and biotechnology. A mentorship programme is also being supported for qualified post-doctoral scientist through in house training by BIRAC through Biotech Ignition Grant. A good level of competence has been developed in R&D in North East Region of the country through mentorship in Biotechnology with a programme promoted by DBT-North Eastern Region-Biotechnology Programme Management Cell (NER-BPMC).

### **North-East Connect in Science & Education**

Well established laboratory plays a major role in science, teaching and education. It is believed that the laboratory is an important means of instruction in science since late in the 19th century. Laboratory instruction was considered essential because it provided training in observation, supplied detailed information, and aroused student interest (Travers, ed., 1973) [34]. The laboratory sciences classes create skills, develop concepts and cognitive abilities, understanding the nature of science - scientific enterprise, scientists and how they work,

existence of a multiplicity of scientific methods, interrelationships between science and technology and among the various disciplines of science attitudes. DBT is promoting science education programme in the North-Eastern region for imparting good science education at school level with the creation of suitable platforms to access modern laboratory facilities. A scheme is being supported for the establishment of "Basic Science Labs in Senior Secondary schools (BLiSS)" across the North Eastern States of India with an objective to promote education in Basic Science at Senior/Higher Secondary level and to attract brilliant students to multidisciplinary research areas. The science lab will be a common lab for all science subjects, which includes Biology/ Biotechnology, Chemistry and Physics. The programme support covers establishment of science based lab facilities and provision of grant for training/workshops including travel cost of experts/faculty members and also a travel support for attending short term trainings within India.

### **Promoting Youngsters in Research**

Systematic and concerted efforts made by the Department of Biotechnology as well as other funding agencies such as DST and UGC have encouraged students to pursue careers in basic sciences to provide the required trained manpower for teaching, research, production and manufacturing in biotechnology. Opportunities for life sciences students exist in agri-based industries involved in production of transgenic plants, seed industries, tissue culture units, agri-chemicals such as biofertilisers, Biopesticides etc., environmental amelioration, pharma industries for diagnostics, vaccine, new drug molecules, clinical research organisations for clinical trials, bioinformatics industry etc. This has to be done at the foundation stage itself. To attract the best brains for pursuing basic sciences, DBT initiated DBT scholarships in biology since 1989 for 20 toppers in 10+2 biology examination conducted by CBSE. This scheme has been expanded to cover State Boards from 2006-07, and the number of scholarships has been increased and made attractive. The Department is providing support for holding national and international seminars and symposia, organising popular lectures by eminent scientists, providing travel grants to students and researchers for participation in international conferences as well as organising exhibitions to showcase products, processes and technologies. These scholarships provide opportunities to young students and researchers for interaction with leading national and international experts which helps in shaping their future career. Proactive efforts by Government with industries to address the gap in skill sets of students are enhancing the employability of students and improving their career prospects.

### **Inspiring the youngsters**

Innovation in Science Pursuit for Inspired Research (INSPIRE) is an innovative scheme, which is sponsored by the Department of Science & Technology for attracting talent in Science. The basic objective of INSPIRE is to create excitement in science and attract talented youth to study science at an early age to build an R&D based human resource pool for strengthening and expanding the Science & Technology system. The scheme supports generation and nurturing of a human talent pool capable of utilizing and developing first principles in science which is both a pre-condition and integral part of innovation and infrastructure. The aim is to create aptitude for research and innovation at

an early age through attractive scholarships for Higher Education and assured career opportunity in research and development. Also Kishore Vaigyanik Protsahan Yojana (KVPY) fellowship programme in Basic Sciences is promoted by the Department of Science and Technology, Government of India, to attract exceptionally highly motivated students for pursuing courses and research careers in basic science. The programme identifies students with talent and aptitude for research; helps them realize their academic potential and encourages them to take up research careers in science, and ensures the growth of the best scientific minds for research and development in the country. The students studying in XI standard up to the 1st year of any undergraduate Program in Basic Sciences namely B.Sc./B.S./B.Stat./B.Math./Int. M.Sc./M.S. in Mathematics, Physics, Chemistry and Biology having aptitude for scientific research are provided fellowships upto the pre-Ph.D. level under KVPY Fellows.

### **Brain Drain/ Brain Gain**

The educational and research fellowship need to be based on relevant quality research and training available in particular graduate programs and for creation job opportunities of a given field. This needs to be supported with mentors by determining and assessing the effectiveness of life sciences and biotechnology programme to make the youngsters entry into the professional career as scientist to address the discoveries in agricultural science to understand soils and their chemistry, new strains of crop plants that are resistant to diseases and yield more food per cultivated acre. Health sciences research need to promote the fundamental understanding of the molecular basis of numerous diseases which has led to the elimination of some and the containment of many. However, there has been great concern with education and research to drive with the placements for the good brain. This has been greatly happening by migrating talents from India to the Western countries and this trend need to be reversed with research promotion (Anon, 1998) [2]. Scientists and professionals working abroad in the area of life sciences and biotechnology can be attracted to come back to India for accepting the research positions for promotion of quality education, research and excellence. The schemes supported by the Department of Science & Technology and Biotechnology though fellowship programmes help brilliant scientists and engineers from all over the world to take up scientific/ research positions in India. The fellowships are scientist-specific and allow them to work in any of the scientific institutions and universities in their discipline. Eligible scientists are given regular research grants through the extramural funding schemes supported by various S&T agencies of the Government of India. Scientists and engineers of Indian origin from all over the world are encouraged to take up scientific research position in Indian Labs through schemes like Ramanujan and Ramalingaswamy Fellowships. A scheme also exists in the area of biotechnology called Ramalingaswamy Re-entry Fellowship supported by the Dept. of Biotechnology for biotechnologists exists to provide attractive avenues to pursue R&D in Indian institutions. In addition in partnership with Wellcome Trust (WT) a global charitable foundation work is being carried out jointly with DBT and supporting the brightest minds and providing fellowships to Indians working outside of India and within India. It is also open to non-Indians willing to work in India their early career.

The greatest challenge in the coming decade is to have talented scientists in many of the faculties for guiding the postdoctoral fellows and junior faculty in the life sciences to take up a suitable carrier. In the past, Indian Institutes and Universities had a significant amount of in-breeding, with former students returning to their prior establishments as faculty members, in sometimes less than fully open searches. While this practice is diminishing, Institutes/Universities must continue to improve their searching/hiring strategies to bring in the best candidates. In addition, newly hired faculty must learn the necessary skills to become successful, such as choosing good research problems and managing their laboratories. The Wellcome Trust/ DBT India Alliance announced generous four-year postdoctoral fellowships (up to 40 per year, starting in 2009), which allow Indians to pursue foreign postdoctoral training in an Indian laboratory. This programme not only provides valuable international training, but also cements a strong connection and possible international collaboration with an Indian laboratory. The young Indian investigators who have already started laboratories in India are making good progress through entrepreneurship development in bio-business.

### **Support by Corporate Social Responsibility and PPP Mode**

Science in the US and Europe has benefited enormously from philanthropy. In India, Wellcome Trust is promoting postdoctoral fellows and faculty. Indian-based philanthropy or private sector funding is less in S&T education and research support. Mahendral Sircar garnered donations to start the Indian Association for the Cultivation of Science in the late 19th century; in the early 20th century, the industrialist Jamsetji Nusserwanji Tata founded the Indian Institute of Science and Acharya Jagadish Chandra Bose founded the Bose Institute. Later in 20th century, the Tata family helped to launch the Tata Institute of Fundamental Research (TIFR). More intensive efforts are required to promote quality education in life sciences and biotechnology through CSR initiatives and PPP mode.

### **Make in India Moment in Life Sciences & Biotechnology**

In make in India movement, India is spreading its wings across different industrial clusters in different streams of education, vocational training, professional research etc. Skill based infrastructure development can enable the youth and professionals to upgrade their knowledge as per the requirements of their job while at the same continuing with their learning process. The focus on skill development in partnership mode with various Asian Countries and developed nations is a step forward for creation of better youth for tomorrow for their assured placements. At present, India is facing lot of challenges in absorbing the educated youth especially in R&D institutions/ industry and the private sector. The graduates and the technicians produced are not well-equipped to meet the needs of the employers. Thus there is need to re-orient the education system to focus on skill based requirement. This is being undertaken in India through tertiary education programs at vocational schools, community colleges, technical schools, ITIs, professional schools, colleges and universities.

### **Conclusion**

India needs to get actively engaged in access, equity and inclusion in science, technology and innovation, both at national and the global level. The science & technology

policy supports the alignment of technological innovation with social values for achieving the meaningful goals. The responsible S&T sector with an innovative approach facilitated developments with partnership mode which led to a New Horizon in education by bringing research excellence through adoption of Responsible Research and Innovation. India is aggressively working towards establishing itself as a leader in industrialisation and technological development. It is becoming an international player in the life sciences and biotechnology accelerating the economic growth to its portfolio. Significant developments in the nuclear energy sector are likely as India looks to expand its nuclear capacity. Moreover, nanotechnology is expected to transform the Indian pharmaceutical industry. Also the agriculture sector is likely to undergo a major revamp, with the government investing heavily for the technology-driven Green Revolution through STI Policy-2013, aspiring for India's position among the world's top five scientific powers. To strengthen foundation in life sciences education, Indian biology education needs to build a new generation with creation of quality at junior faculty level to drive scientific research and education to support the research gap in life sciences and biotechnology education and research excellence. It is also high time to encourage scientists/engineers to work with social scientists through interdisciplinary learning and to understand the need of the community for evolving technology and for absorption by the society.

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