Academic Realities of Biotechnology Education in India

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The article reviews the academic basis of biology-engineering interface, how it is implemented in the West, the anomalies and problems in the prevailing Indian approach aimed to opening many centres to provide education in biotechnology. Many of these Centres do not have useful infrastructure, have little teaching of new biological sciences and are generally managed by inappropriate faculty, mostly with introductory training in biochemical engineering. Training in biotechnology in these centres leaves much to be desired. Producing many graduates in biotechnology to cater for appropriate jobs that do not exist adds to the number of unemployables. All India Council for Technical Education (AICTE) remain complacent. The failure to integrate biology with engineering is the basic issue. For process biotechnology, IIT Delhi (IITD) model for an integrated programme using several biology-engineering interfaced courses is discussed. In R&D, IITD's pioneering studies on bioconversion of biomass to ethanol are cited as research base of the initiatives. The Biology-Engineering Divide, which has been present in the IIT system of education, appeared as an impediment to the creation of new knowledge at the interface of engineering and biological sciences.

The International Union of Pure and Applied Chemistry (IUPAC) described Biotechnology as integration of disciplines, including, molecular biology, microbiology, chemical engineering, process technologies to name a few with the focus very much on application of new technologies emerging from their fusion to the solution of problems for the common good of society. As such, it cannot be defenced as an academic discipline.

Although by various accounts, the biotechnology has been in practice over several years, it is fair to say that it is a relatively new field with renewed emphasis in only the last few decades. Continuous emergence of new technologies has been instrumental in creating highly specialized research themes; however, the short time frames over which they have evolved, have been inadequate to allow their fruits of many of these technologies to penetrate into the very society they are meant to benefit.

Fundamental to the successful extraction of the benefits of a highly applied field like biotechnology is effective education that empowers students the full breadth and depth of the knowledge domains inherent in the subject. Whilst this may appear obvious and clichéd, it is far from clear how many academic institutions are engaging with sufficient commitment to create appropriate and useful degree programmes in the subject. One experiment incorporating those issues has resulted in a unique model for an integrated degree programme in Biochemical Engineering and Biotechnology at IITD. To satisfy the complex needs of such a degree programme, it was essential to design a new academic structure. The planning and implementation took almost 5 years (1984-1989) but has been very successful in preparing students for independent and creative thinking, a skill set that is essential in applying the knowledge grained into real life applications.

Issues and Problems of Biotechnology Education

Preface

The core training of life scientists is fundamentally different from that given to engineers. Mathematical theories and tools, with perhaps the exception of statistics, played a secondary role on the development of the life sciences knowledge base in undergraduate university curricula. While biological scientists may have inadequate background in mathematics, they are very strong in the use of laboratory tools, and, more importantly, in the interpretation of data derived from biological systems. Engineers, with their strong background in the physical and mathematical sciences, are more capable in the testing of theory with experimental responses. The dichotomy in skill sets is a significant gap and can only be adequately addressed where there is a mechanism, through a properly developed multi-disciplinary educational degree programme with a practice component integrated into it.

Knowledge Gap and Academic Compulsions

In India, however, there is a historical absence of proper integration between these two subject areas and has remained as a gap in most teaching materials and methods. Almost all course material and text books treat the biology of cellular systems independently from the engineering of the cell's activities in a controlled and manipulated environment, such as a bioreactor. For example, any discussion on the thermodynamics (steady state balance) and the various rates that matter must address the *in vivo* phenomenon since environmental influence on cellular functions cannot be segregated from the molecular composition and expression.

In contrast, a reaction catalysed by a single enzyme can be more easily described and accurately analyzed as they are more specific and have fewer parameters influencing the overall activity and function.

Students of biotechnology also need to be trained in the inter-relationship between the various cell components from where specific pathway reactions originate. Any known pathway under steady state is considered a single coordinated unit, in which the reactions are connected via a range of intermediate compounds, including metabolites and coenzymes, into an independent whole. It assumes that every single step reaction in the system is under steady state, which in a mathematical context equates to the rate of formation of the metabolite being equal to the rate of its destruction or separation from the system. It, thus, follows that the entire system remains in a closed *in vivo* equilibrium state. Earlier books authored and taught by chemical engineers could not take full account of the challenging issues of *in vivo* reactions in biological systems. In course of the last decade, the emergence of 'metabolic engineering' has taken these issues into additional level of complexities to include fluxes and their controls, reconstructed cells, imposed preference to new substrates and energy flows connected with each step reaction in the network. Also, there are a number of unresolved or at best poorly understood phenomena in biological systems that require informed consideration in the preparation of essential elements of integrated biology-engineering curricula for graduate level teaching of biotechnology. A detailed description of such materials is beyond the scope of the article; however, it is important to understand the scope of the challenge with the breadth of the issues covering such topics as cellular differentiation from single units into multi-cellular organisms to the highly evolved immune recognition systems to surface properties affecting biological functions of proteins. In addition, there is a clear gap in our understanding of the linkage between the genes and post-translational protein processing or what is known as the Central Dogma of Molecular Biology. For rational scale up of mammalian cell reactors, the key question yet, to be resolved, rests largely on the relationship between post-translational processing of proteins to the micro-environment of the cultured cells. Further, ideas on the use of cells and enzymes in low water activity environment (gas phase) are likely to open up new bioprocessing issues in classroom teaching [1]. All these ideas, phenomena and concepts attempting to integrate the laws of life with the laws of physics handled by engineering analysis constitute the basis of the discipline of biochemical and biological engineering and have significant potential for contribution to the class room teaching which is extremely important to young students seeking platforms whose analytical approach may find solutions.

Views in the West

Education in science and engineering on a large scale has always been in continuous upgradation of courses in the universities of USA and Europe, including Russia for more than a century. In the scheme of first degree education in engineering, there is no scope of any formal offering in 'Biotechnology'. Courses in biological sciences can be opted within allowable credit limits. The Master level teaching is substantially advanced and is meant for more exploratory rather than routine learning. The media contributed to the public interest of the benefits and hazards of biotechnology perhaps more than any other area of applied science. Acknowledged impact of new biology in agriculture, animal and human health care, medicine, environment and a large list of drugs and therapeutic products promoted a tremendous awareness in the application of the new science. In view of global acceptance of the term 'biotechnology' and its scope formally proposed by IUPAC, establishment of departments of biotechnology has been seen in many universities in the West excepting USA. For process biotechnology course dealing with production of many biochemical/biological substances in specialized production facilities, metabolic pathways, bioreaction engineering, regulations and control in single cells and their *in vivo* functions, cellular and enzymatic reactions under controlled environment, informatics, separation and purification of metabolites and products, etc., have now become significantly components of biochemical engineering. Besides the academic compulsion, it had a history best exemplified by the story of Penicillin production.

Many European universities established academic institutes as independent units without any mandate for formal teaching but only to admit Ph.D students for interdisciplinary research.

Core Problem: Biology-Engineering Divide

An emphasis on the need for engaging engineering to solve problems of biology was made in the very first inaugural address given to the faculty and students at IITD in June 1970 [2]. The theme addressed two gap areas existing in India: (a) the complete absence of biological sciences in the IIT system's academic curricula, and, (b) a need for research base with a view to demonstrating how an initiative in the research on bioconversion of biomass into chemicals of economic importance could serve as a profound example of biology-engineering productive interface.

Unlike in India, no discontinuity is found in the teaching of biological science from the school to the university stage in any technical university in the world Top schools like MIT, Stanford and Caltech in the USA, the Swiss Federal Institute of Technology (ETH, Zurich and EPFL, Lausanne), Technische Hogeschool (Delft, Holland), Imperial College (London), Technische Universitat (Berlin), Universities of Tokyo, Osaka and Kyoto in Japan and many others are all endowed with powerful departments of biological sciences. Some are even chaired by Nobel Laureates. Today, despite strong faculty and gifted students at the IITs, biology-based curricula is being developed elsewhere. Things have began to change though. Teaching this new science, the very frame of biotechnology, in most cases appear to have proper environment and opportunity to work closely with engineers. Students hardly have any opportunity to acquire knowledge that evolves from intimate interfacing of biological and engineering disciplines. National Academies of Science and Engineering as well as the Boards of Governors of IITs, who are advised by acknowledged leaders in science and industry, took little action towards establishment of discipline of biological sciences in the campus of engineering schools Fortunately, in recent years, new faculty members are bringing in some changes. It is difficult to understand the reason behind the inactivity, but there is no doubt on the critical need to bridge this continuing divide.

Concerning the second point in the address, there was reference to some data and analyses that were presently being documented from studies on retrieval of energy and chemicals from renewable biomass done in several places in the USA and Japan but there was no activity in India in those days. Over the course of the next couple of years, systematic studies in the field began at Biochemical Engineering Research Centre (BERC) in IIT Delhi and emerged into a world leading research centre in biomass conversion to ethanol. However, it became clear that the important limitation was the lack of integrated molecular biology input into the research programme. Despite a clear road map for the project for conversion of cellulose to ethanol via bioconversion, a programme of research and development in which IITD's BERC was in a globally recognized position of leadership in the '70s, the missing link of the biological sciences as an integral part of the knowledge base was a hindrance to this position. Nearly 30 years later, a group at the University of Florida (Orlando) has been one amongst a few other groups to become able to make a success out of a similar research programme through a proper integration of the biology and engineering [3], with support from the US Departments of Energer (DoE), Commerce (DoC) and Agriculture (DoA) and the energy industry. India's programme sadly saw no interest from the industry and the biology-engineering divide continues. It is encouraging to note, however, that a growing number of well trained and skilled molecular biologists, microbiologists and biochemists, working in tandem with biochemical engineers, may become well positioned to take the research activity further to the next level. Given the reality of the global energy situation, the opportunity to re-establish the leadership position is encouraging.

IIT Delhi Initiative

The Background

Nearly three decades ago, IIT Delhi made a small but bold and ambitious attempt to make this shift into Biochemical Engineering. Although Jadavpur University made the first attempt to teach this subject with a major in Food Technology as the first degree level in 1964-65, a proper academic structure was created at IIT Delhi in the form of an M.Tech programme in the department of Chemical Engineering. By all indications, it was a profoundly successful move but not without significant difficulties during implementation. For example, the absence of a biological science department created the distorted perception that recruitment of a qualified microbiologist in the Chemical Engineering faculty staff was a step to promote an individual. Much of the initial success can be attributed to the students themselves, the several bright Chemical Engineering B.Techs from other IITs and universities joined the programme with the realization that biochemical engineering was one clearly promising areas of high impact that Chemical Engineering could be seen to make.

Infrastructure and Resource Development

Academic collaboration with several top UK universities played an important role in this endeavour at IITD to help create special facilities and infrastructure. In 1971, a very large and long term academic support and financial grant was secured from the Alma Mater of the author, The ETH, Zurich with the objective of providing training of the research staff in biological science in Switzerland. In appreciation of the ETH's unique proposal, a matching grant was allocated by the Ministry of Education for additional building, research staff, uninterrupted supply of utilities and a documentation unit to quickly elevate the IITD project to a workable status. The collaboration continued with continued success and a number of significant milestones were recorded during the life of the project, including:

- Creation of the Biochemical Engineering Research Centre (BERC) in 1976 under which the entire research and academic activities were brought.
- Recognition of the IITD's training programme as the role model for the developing countries by the UN Conference on S&T for Development, held in Vienna in 1979.
- Financing of a pilot plan facility (1982-86) for scaleup of the ethanol from biomass project of the Indo-Swiss collaboration by the Department of Non Conventional Energy Sources (DNES). (Financing this project rendered a US$ 5 million offer from UNIDO for the same project unavailable as DNES felt the Indian initiator should remain in India).
- Funding from the French Foundation of Solar Energy Research Paris (COMES) for facilities to conduct two international workshops on rDNA technology applicable to cellulose depolymerisation enzyme systems.
- A 5-year UNDP grant (1984-1993) for supporting continued training of BERC's faculty and technical support staff at several universities and research laboratory in the USA, Europe and Japan.

Two decades of training and research at BERC, IITD produced a critical faculty research and support staff trained with new knowledge in the analyses of several enzyme catalyzed reactions, principle of bioproduct separation methods and process development in a number of universities and industries in the USA and Europe. With these new resources, IITD was ready to undertake an academically appropriate and good model for imparting education and training to students admitted through the IITs' JEE system and also to register research students.

Evolution of an Academic Model

The true emergence of a novel multi-disciplinary programme resulted from a proposal to convert the one and half year M.Tech into a 5 year integrated M.Tech programme in Biochemical Engineering and Biotechnology, with entry through the JEE selection process. The proposal, submitted to the Ministry of Education, incorporating new courses in biological sciences interfaced with engineering and was evaluated by various internal committees and international experts engaged in teaching and research in chemical engineering, process engineering, biochemistry, molecular biology, genetics, microbial physiology, metabolic regulation and control of bioseparation. Following senate's clearance and relevant amendments in the IIT Act, the proposal was passed by Parliament. Admission of the first batch of JEE selected students into the programme began in 1989. In the course of the next few years, the programme fell in line with the Dual Degree scheme of a tandem 4 year BTech + 1 year M.Tech. The successful graduates of this scheme were entitled to receive both the degrees (B.Tech + M.Tech) only after completion of all credit requirements through five years of continuous study.

Between 1974 and 2005, 379 students qualified for M.Tech degrees and 77 research students received Ph.D in Biochemical Engineering and Biotechnology.

Now, over 30 years later, the trained Bioscience Engineering graduates from the IITs have become high value resources in the global biotechnology market. Based on various indicators, it is recognized that IITD's experiment to produce biotechnologists, having acquired adequate engineering skills, has been successful. The graduates are occupying positions of authority in industry and academia, mostly in the US, with many venturing into startups bringing highly innovative ideas to an extremely competitive market. Universities in the Western world have been offering good financial support and opportunities to pursue Ph.D research to which the skills and training provided during their IITD education have proven highly valuable.

Followup by All IITs

In 1986, IIT Kharagpur introduced its first three semester M.Tech scheme in Biotechnology and Engineering in the Department of Chemical Engineering. It eventually evolved with academic supports provided by several departments of science and engineering, including agricultural engineering, into a Dual Degree programme of five and half years. At some point of time, it also permitted lateral entry into the one and a half year M.Tech scheme for graduates with applied science background. Currently, under a new Department of Biotechnology, IIT Kharagpur is running a four-year B.Tech, five year Integrated M.Tech and a three semester M.Tech in Biotechnology and Biochemical Engineering. Academic programmes now followed at IIT Kanpur, IIT Bombay, IIT Madras and IIT Roorkee have the same objective and vision to train engineering scientists for biotechnology. For IIT, Guwahati, the original plan was to establish a strong Department of Biological Sciences, not existing in any other IIT, to firmly bridge the Biology-Engineering divide. But for some reasons, this plan was abandoned, and instead, a Department of Biotechnology with similar academic structure followed in other IITs was adopted. Thus, the absence of Biology-Engineering integration situation, inherent in the divide, continued and Guwahati gaining a distinction was missed.

Indian Situation

In contrast to the developments at the IITs, in particular IITD, the structure and content of the academic curricula for imparting graduate training in biotechnology, pursued at most other places in India, leaves much to be desired. The mushrooming of courses in Biotechnology offered by many Indian universities and regional colleges reflect a market demand for graduates trained in the discipline – students are attracted to these courses based often on the word in town that 'Biotechnology has a great future'. It is highly doubtful, however, whether the level of training these courses offer are able to adequately address the skills demand. It is important to mention that many students admitted and trained under inadequate facilities in biological/ biochemical sciences but having acquired more analytical skills in engineering are offered good positions and adequate salaries by IT industry which is booming. This is true in such lesser extent for IIT products with balanced exposure to courses in bio and engineering science areas. Students trained in more bio courses but found weak in physical and analytical science courses do get opportunities as laboratory scientists mostly for routine jobs.

Many reasons can be attributed to the general lack of ability to impart appropriate levels of biotechnology education modeled on the IITD structure. One genuine difficulty lies in the non-availability of professionally qualified teachers with appropriate level of research experience. Also, most places are unable to invest the kind of fund required for adequate infrastructure. Much of the training in biotechnology is delivered by people with limited understanding of the importance of chemical sciences on molecular genetics or lack the analytical ability background required in rendering new knowledge into biotechnology. Thus, the quality and content of the training provided through Biotechnology programmes remains largely unquantified.

The lack of resources and real vision for the future have created a situation that leads one to ask the question whether the biotechnology industry can gainfully employ such graduates for their conceptual understanding and innovative ideas and not just as glorified technicians. Will the level of education and training of these graduates be sufficiently attractive to employers or is there a serious risk of adding to the country's educated unemployed cadre?

Two recent observations, not necessarily attributable to the dichotomy in biotechnology education in India, have been made that may warrant urgent attention: There is (a) an absence of interest from highly qualified and trained young biochemical engineers and biotechnologists that is creating a less than desirable opportunity for inappropriately trained individuals to take up teaching positions, and, (b) industry employing such graduates are only suitable for routine analytical jobs. This is not to suggest that there is not a need for skills at these levels; indeed, there is a sizeable opportunity, for example, in the business of pathological diagnostic outsourcing, which has, by nature of the business, less intellectual content than say a drug discovery research in a biotechnology company. As an example, it is estimated that from the UK alone nearly $900 million annual business in diagnostic research may be available for outsourcing from India.

However, to be a true global player and realize its goal of a multi-billion dollar biotechnology industry, companies must operate higher up the value chain for which its human resource requirement will be based on more than a degree in Biotechnology. Without a major paradigm shift, that will help to produce a few leaders in this emerging discipline, there may be disappointment for Indian biotechnology reaching a position comparable to what computer science and engineering has been able to achieve, and, in fact, they are serving as standby employers. A few Indian companies that are developing novel technologies generally employ graduates of IIT, if available, and a few others trained abroad, but such efforts are limited. IIT-qualified graduates, even if they decide to work in India, constitute a small fraction of the man power requirement.

The leadership situation in respect of training in biotechnology remained like an unmanned crossing despite considerable buildup of infrastructural facilities at some institutions over the last two decades. Unfortunately, many of our bright graduates refuse to consider university teaching as a career, and given the opportunity, most of them would leave for green pastures abroad. Further, in many cases, efforts in R&D seem to have gone back to the days of empiricism, as if no knowledge existed. As a result, creation of new knowledge remains difficult in the present scenario, despite abundance of documented information. Some graduates, who left the country years ago, do return but mostly as representatives of large multinationals to look after the companies, Indian business. Thus, all the agencies responsible for creation of human resources and new knowledge, and, engaged in providing financial supports need to review the situation critically to be able to determine the economics of investments and success achieved in producing the desired talented manpower in biotechnology. The fact remains that the first five IITs, which came up in the decades of fifties and sixties, have been nurturing an excellent base for higher education in S&T.

Concluding Comments

Biochemical engineering is important and essential in process biotechnology. Its multipoint presence and the advances made around the world in course of the past three and half decades improved the possibilities of innovations in mass cultivation processes and creating optimized pathway to reach the target product. It demonstrated the importance of viewing bioprocess as an integrated concept for improving the efficiencies of up and downstream processing harmonically. Its professional significance is reflected in recently created Society of Biological Engineering (SBE) by the American Institute of Chemical Engineers (AIChE) to cover new frontiers of biotechnology. In Europe, it is already seen as a rapidly expanding industrial activity and is professionally supported by The European Federation of Biotechnology (EFB).

A significant outcome of the Indian initiative emerged from the VII International Biotechnology Symposium (VII-IBS), sponsored by IUPAC and hosted at BERC (Feb. 1984) under the auspices of the Indian National Science Academy, where a key recommendation effectively led to the establishment of the Department of Biotechnology under the Ministry of Science & Technology.

Good education and training are the foundations for application of new knowledge to the benefit of society. Human resource development in any technology and high skilled discipline cannot be taken for granted. It requires regulation and control to sustain the academic rigour and intellectual development. The current approach does not appear to be consistent with the demands of quality and size of manpower requirements in the biotechnology area to make India competitive in research that yields new products and processes. Academies and professional societies in developed countries, with significant and direct input from industry, have debated their views to allow informed policy decisions of national importance to be made in science and engineering. Hopefully, similar societies in India will also engage in active dialogue.

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