Is this emphasis on the research growth of the centres justified? Are not the universities primarily for education and not research? Somehow the image that education, at least at the post-graduate level, can go on in the absence of high-powered research appears to be an original Indian thought, that too of recent origin. Even the original charter for Indian universities has not segregated education from research so effectively as we have now achieved in most places! In the absence of a stick, the carrot of research support may help change or maintain the pace

Some of these considerations may be true of all universities and all subjects. It may be true that not all subjects can be developed equally. Since progress is sporadic and not normative, why worry? Some progress is better than none. Biotechnology, if sustained in terms of its intrinsic logical growth, may yet offer a reasonable and plausible model for an improvement of the general scenario of education in the country. That will be a true beginning. But it will require considerable planning for the years ahead.

Acknowledgements I claim no originality for many of the opinions expressed herein I am indeed grateful to many of my colleagues and students, past and present, who provoked me constantly to rethink on any stand I have attempted to take There has been more to learn than to impart

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Biotechnology training—innovative teaching and liaison with industry, MSU Baroda

V. V. Modi

Teaching should stimulate students to ask intelligent questions and seek ways of answering them. Biotechnology education cannot be limited to textbooks.

Biotechnology today has become synonymous with application of state-of-the-art molecular biology in industrial ventures; it deals with the use of microbes and plant and animal cells in the production of a wide variety of substances. For example, genes encoding penicillin-biosynthesis enzymes have been isolated and cloned[1]. Such cloned antibiotic-production genes can be used to develop antibiotics with modified structure or as probes to isolate from the soil other microbes that make similar but subtly different antibiotics. Genes for an antibiotic can be transferred into, say, a new host bacterium that ferments well at 40–50°C to investigate the feasibility of antibiotic production at high temperatures; the reduction in requirements of cooling water in the process could result in considerable cost savings. This can happen within a few years The impact on medicine and industry of the new technical ability to analyse, synthesize and rearrange DNA and to exploit monoclonal antibodies will exceed the most optimistic claims. Very soon deeper understanding of the organization and functional control of human chromosomes will emerge. We can ignore these developments only at our cost.

Planning for a work-force

There was clearly a need to train students and expose them to these developments. In 1984 the National Biotechnology Board (now the Department of Biotechnology, DBT) promoted and nurtured the establishment of specialized schools at more than a dozen centres, including the M S. University of Baroda (MSU), University of Poona, Jawaharlal Nehru University, Madurai Kamaraj University, Banaras Hindu University, Jadavpur University, the Indian Veterinary Research Institute, the Indian Institutes of Technology at Kharagpur and Bombay, the Indian Agricultural Research Institute and the All-India Institute of Medical Sciences. Universities were selected for support on the following criteria[2]: (i) appropriate existing expertise, (ii) infrastructural facilities, (iii) established research strengths in designated areas, (iv) major grants received from other funding agencies, and (v) proximity to research institutes or national laboratories already engaged in biotechnology.

On an average about 15 students are admitted every year at each of these centres to the master's-level teaching programme. Selection of candidates is done on the basis of an all-India open test, after which successful students are distributed among the centres according to merit and choice of centre.

MSc biotechnology at MSU

The course work includes theory classes in general microbiology, immunology, biochemistry, biophysics, biostatistics, developmental biology, basic genetics, pollution control and biodegradation in the first year. In the second year the emphasis is on genetics and molecular biology, genetic engineering, industrial and applied microbiology, advanced immunology, plant tissue culture and economically important plant products. These subjects are taught by staff specializing in the respective subject. Several academic positions were specially created for the biotechnology course, and, when required, cooperation from staff of other departments on the campus is also sought.

Suitable laboratory work including experiments designed to give the students a deeper insight into their theoretical knowledge, with focus on microbial biochemistry, immunology, developmental biology, fermentation technology and genetic engineering, is carried out.

As a part of laboratory work, dissertation problems are given to students on some aspect of ongoing projects. This gives them opportunities to come in close association with teaching staff and to work with committed research students. In a wholesome environment the M Sc students learn to do hard work enthusiastically, ask the right questions, take pains in verifying facts, and acquire some sort of refinement

Feedback to teachers

Education in biotechnology in particular and modern biology in general is not limited merely to textbooks and lectures, but proceeds through a number of innovative approaches in teaching. At MSU, strong emphasis is placed on the complete involvement of students in both theory and laboratory courses, by way of regular interaction with staff, research students and other postgraduate students. The aim of teaching is to improve the intellectual and technical performance of students. How does a teacher know that the student has learnt, with understanding, the material that he has taught? In the biotechnology programme at MSU, we organize a monthly question hour referred to as 'brains trust'. During this exercise questions that pertain to material taught in the classroom are posed to the students in the following way.

M Sc first-year and final-year students compete by answering these basic questions. The third group, viz. staff and research students, put the questions to the final-year M Sc students, and the latter, in turn, put the questions to the M Sc first-year students. One point is awarded for a correct answer to the student. In case he or she is unable to answer and the immediate neighbour answers, a half point is awarded to the team. Failing this, if any of the remaining students from the team answers the question, the team gets 'zero' point. Failure to answer by the team results in a negative point, and the questioner has to provide the answer. This game not only develops the ability to answer a question precisely but also develops the student's ability to ask pointed, concise and pertinent questions. It is a good evaluation for the staff as well, because, if, on the whole, a team has not performed well, they can decide that an extra tutorial in a particular topic may be helpful. This approach provides the appropriate cognitive feedback from the students to the teachers and results in positive reinforcement of teaching material.

Evaluation

Continuous assessment in the form of weekly tests is practised. Fifty per cent of the final scoring is decided from these tests and the remaining is assessed in a three-hour written examination at the end of the course. Laboratory work is assessed throughout the year.

Apart from these, efforts are made to develop the reasoning capacity of the students in the subjects of modern biology by posing to them problems pertaining to these subjects. The approach taken by the students in solving these problems is often an indicator of the extent of their understanding and the interaction between the teacher and the students.

Similarly, the exercise of giving seminars on selected topics in contemporary biology trains the student in systematic presentation of scientific data and improves the student's faculty of expression. Credit in dissertation and presentation of scientific material and seminars is given for methodology of investigation, summarization, response to questions, and appropriate citation of references.

Additional teaching inputs

Frequently a workshop is held during the two-year course, with an exhaustive treatment of a particular subject by way of experiments and lectures and discussion. Such workshops have been conducted by persons who specialize in a given field, such as immunology or biochemical engineering.

Talks by visiting scientists are held as often as possible. Students are encouraged to join visiting faculty at lunch/tea. This is aimed at achieving the following: a deeper insight into a particular topic, exposure to work conducted in other laboratories in the country and abroad, and stimulation of students' thought processes to enable them to analyse the talk and ask intelligent questions.

Success and shortcomings

Though biotechnology is advancing by leaps and bounds, its advent in our country is only recent, and teaching at various selected centres is still in the developing stage. By the mid-nineties we should be able to feel the impact.

A large number of the bright science graduates continue to be attracted to biotechnology. This is vital to our plan to avoid a shortage of skilled biotechnologists in the future. At MSU, so far about 70 students have earned the master's degree. Most of them are working for PhD either in India or abroad. A few have joined industries. Some are in research organizations like the Bhabha Atomic Research Centre (BARC) in Bombay, or laboratories of the Indian Council of Agricultural Research (ICAR) and the Council of Scientific and Industrial Research (CSIR). It may be noted that M Sc biotechnology degree holders from India have done very well in national and international competitive tests.

Industrial organizations are not adequately prepared with their R&D setups to exploit the new ideas and resources. There is another drawback—many students, as well as some seniors, feel that biotechnology is 'cloning and genetic engineering'. Biotechnology is more than that: it is an amalgamation of the basic information concerning recombinant DNA, the new research techniques, and technology to generate marketable products. One can produce almost any protein by genetic manipulation. But on an industrial scale one must have a knowledge of bioreactors and upstream and downstream processing methodology to produce active products such as interferon in pure form and high yield.

Relationship with industry

In an applied area of activity like biotechnology, academic institutions cannot operate alone. It is imperative to cultivate links with industry and examine if each party is taking the other's needs into consideration as effectively as possible. At the moment this is our weakness.

Intimate relationship over many years between university chemistry departments and profit-oriented companies created the vast chemical industry the world over. The same is true for physics and engineering departments and the electronics industry.

I am reminded of the isolation of reserpine from *Rauwolfia serpentina* by Ciba Pharma of Basle in 1950. Prior to the announcement of this work, a great deal of pioneering work had been done on this plant in India. On account of its reputation in the traditional systems of medicine work had been carried out on the chemical constituents of *R. serpentina* by S. Siddiqi at the Tibbia College, Delhi; on its clinical use by B. B. Bhatia at the K.G.'s Medical College, Lucknow, and J Vakil in Bombay; and on its pharmacological properties by R. N. Chopra and B. Mukherji in Calcutta. But as each Indian group had worked independently the credit for the discovery of the pharmacological property of reserpine went to Ciba. This underscores the need for intimate collaboration between biological chemists, pharmacologists and clinicians for work on new drugs.

The scenario has not changed much since 1950. We need a far stronger industry–academe liaison, a permanent forum, where a coordinated exchange of ideas can take place.

Cooperation

At the research level much strategic work remains to be done. On the basis of a market survey we should discuss 'What are the pharmaceutical and agricultural products in which we are interested?' Also a great deal of meaningful and dynamic cooperation is required between DBT, the Department of Science and Technology (DST), CSIR, the Department of Atomic Energy (DAE), the Indian Council of Medical Research (ICMR), ICAR and biotechnology teaching and research centres. Will the government give a positive lead either directly or through DBT? Our national academies and scientific societies organize meetings and publish journals, their unwillingness and incapacity to interact with the government on such issues at the political level shows ostrich-like behaviour.

The coming generation will need a new music. Pathfinders in biology will seek new avenues to solve challenging problems. The training programmes are the hope of the future.

1. Smith, D J., Burnham, M K. R., Edward, J., Earl, A J and Turner, G., *Bio/Technology*, 1990, 8, 39.
2. Modi, V. V and Lloyd, D., *Ind Biotech.*, 1989, 9, 18

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Bioprocessing—the need of the day

Kunthala Jayaraman

Biotechnology training should also aim to produce bioengineers.

The introduction of postgraduate programmes in biotechnology sponsored by the Department of Biotechnology has given a tremendous boost to the teaching programme in modern biology. This is akin to the concentrated efforts made for the development of the atomic energy programme thirty years ago. It is an astute move in the groundwork to generate manpower for R&D in this area. The approach of concentrated funding in a few well-developed centres appears to be the most logical one for achieving major impact. I recall the strong opposition we faced against the introduction of molecular biology in the curricular programme in biology twenty years ago. Thanks to the news media, the awareness of the students and the public of this modern and exciting era of science has risen sharply. That is why the change has been made easier, and the 'old guards' of our educational system had to remain silent!

The research and teaching programmes in biotechnology take into account the diversity of educational backgrounds required to tackle technological problems in biology. Currently there are excellent pockets of research in molecular biology and basic genetic engineering, and some application-oriented programmes in diagnosis of infectious and tropical diseases and plant genetic engineering. However, there is the major lacuna of absence of active interaction between 'gene engineers' and process technologists. The latter group of specialists usually comprises biochemical engineers and instrumentation specialists with computational skills. While the chemical industry's requirement is quickly filled because of the fairly straightforward nature of the processes, in the biotechnology industry, where processes depend on biological systems, the complexity of the reactions makes process control technology more sophisticated and process parameters more diverse. There are a few centres in India where emphasis on chemical-engineering applications in biotechnology is seen, but a healthy amalgamation of gene engineers and biochemical engineers is not seen.

The curriculum in biotechnology at the M Tech. level at Anna University in Madras aims precisely at this amalgamation process. There is a need for us to train bioengineers who can handle production of recombinant vaccines, monoclonal antisera in tissue-culture reactors, fermentation processes for pharmaceuticals, etc. The Anna University curriculum aims at training chemical engineers (B Tech graduates) in biological systems and introducing chemical-engineering principles to biologists (M Sc graduates). More such interaction should be established in the excellent centres in basic sciences so that biotechnology product development from laboratory to commercial level can become feasible.

A weak link in the industrial application of research programmes is the absence of pilot-scale validation facilities. As mentioned earlier, complex parameters governing the production of biomolecules in bacterial fermentations, animal cell cultures and plant tissue cultures demand a whole set of studies, and only a 'hands-on' approach can enable scale-up of these processes.

Another area that requires special attention is use of the trained manpower. One often sees that many of the youngsters coming through these educational programmes leave the country as soon as they have learned the basic techniques. There should be innovative measures to hire them as soon as they come out of these educational institutions and not subject them to a plethora of delays and bureaucratic procedures.

The last but not the least is the problem of consumables and materials for day-to-day work in biotechnology. Unless concrete measures are taken to solve these problems, the enormous amount of money spent on purchase of equipment and establishing laboratories will not give tangible returns.

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