The nature and scope of industry–institute interaction in India

Experiences from the Indian Institute of Technology, Madras

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One of the most important functions of a modern research university is interaction with industry in order to establish a close link between education, research, and professional practice. This paper examines relevant issues with special reference to the Indian context: Indian industry's perceptions of the curricula offered by the universities; the prerequisites for an institution if it is to develop successful cooperation with industry; the interaction between scientific and industrial research organizations and industry; and basic differences and contentious issues that arise between the higher education and industrial sectors in terms of roles, goals and perceptions. An analysis is also presented of some barriers or inhibitors to cooperation, and strategies to overcome them are suggested. Against this background, the author offers a case study of current initiatives designed to promote interaction with industry at the Indian Institute of Technology, Madras.

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Many engineering educators have stressed the importance of the synthesis and integration of knowledge, and of establishing a much closer link between education and research and professional practice. They have also emphasized the need to expose students to 'real' engineering at the same time as teaching them the fundamentals. This paper examines the nature and scope of industry–institute interaction in the context of engineering in India and discusses relevant issues. A case study of the Indian Institute of Technology, Madras is presented to highlight the policy initiatives and experiences of an institution which considers interaction with industry as one of its mainstream functions.

Industry's perceptions of the curriculum

A questionnaire-based survey and analysis was performed recently in order to determine the profile of an Indian engineer.[1] The main motivation for this research was to examine the frequent criticism from industry that graduate engineers have no industry orientation – that universities produce 'engineering graduates', not 'engineers'. The questionnaire covered the following six major functional areas which are applicable to the majority of branches of engineering: design; development; production/construction; operation/maintenance; services; and testing/certification. In each area, several main tasks were identified, and a comparison was made between the availability of competencies at job-entry level and the requirements for performing the job competently. The competencies included knowledge, abilities, skills and attitudes. The comparison indicated the extent of the gap between expectation and availability, and enabled the identification of areas of match and mismatch. The survey covered 52 manufacturing industries (employing 10,544 engineers), 22 service industries (employing 6,743 engineers), and 2 R&D institutions (covering 94 engineers).

The major deficiencies related to knowledge about the industrial environment: statement of objectives, policies, targets, turn-over; use of negotiating skills with employees and clients; adoption of appropriate channels and forms of communication; understanding of social–psychological culture in industry and business; and knowledge of factory acts, statutory requirements, etc.

The first issue to be considered once the major gap has been identified is: who is responsible for remedying it – industry or university? The guiding principle, of course, is that the university is the provider of basic knowledge, and industry is the place for applications, commercial and economic considerations, codes, specifications, etc.

Another important finding of this study was that, when the specific requirements of two major industries – one in the manufacturing sector and the other in the service sector – were compared with the average requirements of industries in each of these sectors, it emerged that individual industry requirements were very different from the requirements averaged over all industries. Thus it is not in the larger interests of industry to expect 'tailored' products from university.

Current issues in India

Not every institution can have effective interaction with industry. There are certain prerequisites: faculty with expertise and commitment; an adequate physical infrastructure, in terms of library, labs, computing facilities, etc; a conducive academic environment; bright students; and promotional policies to develop interactive activities. As with industry in other developing countries, Indian firms depend heavily on imported technology – correspondingly their dependence on Indian higher education is low. Engineering institutions belong to the educational sector, and receive funds from the Ministry of Human Resource Development (MHRD). No funds are received directly from industry, and the functions of universities are not determined with specific reference to industrial needs.

In order for industry–higher education interaction to become effective, it is necessary to institutionalize it, and facilitate the interaction through the allocation of appropriate physical and human resources. It cannot be left to the initiatives of individual academics to develop a culture of cooperation between education and industry.

There is a need for institutions to have a Centre for Industrial Consultancy and Sponsored Research, which would constitute a 'single-window operation' or 'one-stop shop' for external clients. The Centre should have around 7–10 full-time professional staff and appropriate support services. It should have access to the expertise of lawyers and patent attorneys, and of professionals capable of efficient interactive project management.

The majority of academic technology is rarely ready to be commercialized, while what industry needs, and what it can exploit, is demonstrated technology with commercial potential. Technology transfer is a long and tedious process, especially when it requires scale-up and adaptation.

Interaction between SIROs and industry

It is not only academic institutions, but also scientific and industrial research organizations (SIROs), such as the labs of the Council for Scientific and Industrial Research (CSIR), which are found to be wanting in strong links with industry. In a meeting organized by the Department of Scientific and Industrial Research in October 1992 in Delhi, the following recommendations emerged:

- There should be initiatives from both sides for the identification of collaborative projects.
- Emphasis should be placed on 'club' or 'consortium' projects of common interest to many industries; for example, in areas relating to emission control or noise reduction.
- There must be recognition on the part of the research sector of the need to fulfil commitments in terms of time and goals, and to maintain confidentiality.
- There should be faster absorption in India of imported technology.

Role of professional societies

Professional societies are in a unique position to bring academics and professionals together, and to foster interaction between industry and higher education institutions. However, the major professional societies in India currently place undue emphasis on their associate membership examinations, and neglect other opportunities. They should strive to adopt strategies to improve interaction.

Barriers to interaction

The barriers to more effective industry–higher education cooperation in India are both technological and managerial. The following is a list of the most significant impediments:

(a) Lack of a 'one-stop-shop' approach to interaction and technology transfer, exemplified by: lack of coordination; confusion as to individual responsibilities; inefficient organization; indifferent public relations; and duplication of control mechanisms.
(b) Interaction with industry and technology transfer are not regarded as core or mainstream activities for higher education institutions.
(c) Lack of administrative facilities and resources.
(d) Lack of resources for market research and marketing.
(e) Lack of promotional literature to encourage cooperative ventures.
(f) Absence of development funding to take exploitable technology from 'proof of concept' to 'demonstration' stage.
(g) Industry differs significantly from academe in the following respects: it has relatively straightforward goals; it must make a profit; it is concerned more with short-term goals; it places more emphasis on timely results, and less on sound fundamental understanding.
(h) Engineers in industry may be unfamiliar with theory, but faculty must recognize that they have accumulated a vast reservoir of experience and with it have acquired much empirical knowledge.
(i) Before a professor can be useful as a consultant, he or she needs to receive a lot of information from industry, but there is often considerable reluctance on the part of industrial experts to share their information with academics, even though the resulting interaction would be mutually beneficial.
(j) The part-time commitment and partial availability of university professors are frustrating for industry.
(k) Industry is often concerned about untimely disclosure of proprietary information or loss of control over work in a university.
(l) Engineering faculty are often reluctant to work with industry, for the following reasons: the ivory tower complex; they are too busy and it is not worth the trouble and bother; the possible benefits are not recognized; there is a feeling of incompetence in a new environment, of not knowing where to start; and universities do not provide incentives or rules to encourage faculty involvement with industrial problems.
(m) Industry usually makes decisions on the basis of information available rather than on the basis of complete solutions.
(n) There is a mutual under-estimation of each other's strengths.

Strategies to overcome the barriers

The following considerations are crucial to the strategic elimination of the impediments listed above:

(a) Criticism concerning the relevance of academic research can be overcome only if interaction with industry and technology transfer are recognized to be core or mainstream activities for universities – as important as manpower development.
(b) No collaborative activities can succeed without the active support of the highest levels of management.
(c) A database of expertise and facilities needs to be created and maintained.
(d) Industry and business need to be convinced that direct support for technology development is at least as important as marketing, to which they allocate substantial resources.
(e) Structural mechanisms should be created for the continuous two-way flow of useful information, equipment, manpower, funds, etc.
(f) Industry and universities should consider the education and training of engineers as their shared responsibility. It is necessary, in this context, to understand the principal distinction between education and training. Education is an open-ended process leading to the development of the mind which involves inputs in the cognitive and affective domains. The specific goal of training is to impart technical skills, which involves inputs in the psychomotor domain. It is logical to conclude that education is the responsibility of universities, while training is the responsibility of industry.
(g) Institutions should encourage faculty to direct their R&D efforts to indigenous industry needs.
(h) The initiative for industry–university interaction must come from the university; it is evident worldwide that industry is often a reluctant partner.
(i) Industry must give its staff time to learn from universities; academics must invest time to learn from industry.

(j) Co-op undergraduate and postgraduate programmes have potential benefits for students, faculty, university and industry.
(k) Emerging IT technologies must be harnessed by educational institutions.
(l) In the face of globalization, international competition, and a scarcity of resources for both industry and university, collaboration will help in pooling, sharing and optimizing the use of available resources.
(m) Interface offices or organizations must be established in both sectors, staffed by motivated and committed people.
(n) The rules and regulations governing industrial firms and higher education institutions must be designed to promote interaction.

Contentious issues

There is a variety of problematic issues of compatibility which stem from the different environments and cultures in which each sector operates:

(a) Industry expects immediate solutions to its problems. It is impatient with academics who cannot devote full-time attention to its needs.
(b) Industry expects students to have had exposure to industry before graduation – but few Indian firms are prepared to undertake the required commitment.
(c) Industry would like to have a say in the design of curricula; however, few industrial personnel will devote time to meetings and to the preparation of instructional resource materials.
(d) Opportunities exist for faculty to work in industry during vacation, but there are few takers. There are many reasons for this, including indifference and irregular academic calendars.
(e) While university professors are keen to provide continuing education programmes for industry personnel, they balk at committing time themselves to learn about industry developments and practices.
(f) There is a mutual lack of appreciation in industrial organizations and higher education institutions about their respective roles and functions, leading to misunderstanding, lack of confidence, and even contempt.
(g) There is some misuse of consultancy by academics, which is detrimental to the fulfilment of academic responsibilities.
(h) Many industry experts are poor communicators, while many university professors are poor consultants.
(i) Industry is often concerned about secrecy and confidentiality; this is particularly true of small companies.
(j) The nature and scope of R&D in universities is determined largely by academics' perception of 'peer' recognition. The yardsticks for most promotions are international publications and the opinions of international peers.
(k) The commercial exploitation of university research requires an intermediate agency for the transformation of concepts, theories, and prototype development into industrial products and processes.
(l) The normal timeframes in industry are quite different from those in universities.

Points of caution

From the point of view of the university, there are certain potential dangers in collaboration which need to be addressed.

The dual roles of faculty as teachers and consultants can result in conflicts of interest and distortions; this is a worldwide phenomenon, and there have been instances of faculty misusing their role as consultants by neglecting teaching responsibilities. In fact, medical professors in India are given a non-practising allowance so that they can concentrate on their academic duties. There is a window for consultancy activities during a faculty member's career – after acquisition of knowledge and experience, and peer recognition of competence. However, it must be realized that, more than consultancy, it is R&D that determines expertise or competence.

In addition, the university must balance visible outcomes in terms of consultancy earnings with intangible benefits in terms of education, research and scholarship. All faculty cannot be expected to perform all functions; the institution must promote individual strengths. The bottom-line in all university activities, whether teaching, research, consultancy, technology development, or continuing education, is determined by quality and relevance.

Tables 1–5 provide a summary of the differences between universites and industry in India, as discussed in the preceding sections of this paper.

Case study of IIT Madras

History

In the first decade of its existence, the principal focus of the Indian Institute of Technology, Madras (IIT Madras) was manpower development. In the second decade, an

Table 1. Areas of dissatisfaction and misunderstanding between universities and industry.

Industry about institutions	Area of concern	Institutions about industry
1. Institutions produce engineering graduates, not practising engineers. 2. Students learn only theory, largely unrelated and irrelevant to the solution of industrial problems.	Students	1. It is unreasonable of industry to expect 'tailor-made' products, and it must accept responsibility for orienting new recruits according to its requirements.
3. Faculty possess only bookish knowledge: they should spend periods in industry. 4. Too many academics are chasing problems irrelevant to Indian industry. 5. Things are different 'out here in the real world'. 6. Partial commitment and part-time availability of academics is frustrating.	Faculty	2. A considerable proportion of work in industry is routine, unexciting, and does not involve advanced technology. 3. Indian industry is more dependent on adopting/adapting foreign technology than on indigenous technology development. 4. Industrial consultancy is just one of the responsibilities of academics. Industry is not sufficiently concerned about the thorough investigation of problems, but demands instant solutions, even if these are only approximate and incomplete. This goes against the central purpose of R&D as academics perceive it.
7. Institutions have no appreciation of timeframes, and they are too bureaucratic.	Systemic issues	5. Industry demands short-cut methods which cannot be accommodated. While they put up with foreign consultants, they are inconsiderate towards university professors.

Table 2. Complementary roles for industry and institutions.

Industry – strengths and resources	Relevant area	Challenges for institutions
1. Stock of practical knowledge and skills; wealth of experience. 2. Topics and problems for project/thesis work.	Students (sandwich programmes; lectures by industry professionals)	1. Lack of industrial exposure and relevance.
3. Wealth of practical knowledge and experience. 4. Funds for R&D. 5. Experts with specialized knowledge. 6. Strategies for enhancing productivity and quality. 7. Manufacturing facilities; hardware.	Faculty (sponsored R&D; consultancy; short-term secondments; lectures by industry professionals)	2. Lack of awareness and knowledge of industrial practices and needs. 3. Inadequate funds for R&D. 4. Lack of industrial orientation in lectures. 5. Lack of correlation between theory and professional practice. 6. Lack of awareness of employment opportunities for students. 7. Lack of understanding of the role of industry professionals.
8. Direct contribution to industrial production and development. 9. Funds for the support of mutually beneficial activities.	Systemic issues (curriculum development; endowments; industry chairs)	8. Lack of industrial orientation in the curriculum. 9. Inadequate funds for various academic activities.
Institutions – strengths and resources	**Relevant area**	**Industry needs**
1. Educating competent manpower.	Students	1. Manpower.
2. Academic and sponsored research, consultancy expertise. 3. Specialized knowledge in areas of expertise.	Faculty (sponsored R&D; consultancy; joint projects; continuing education)	2. Access to timely R&D results and information. 3. Solutions to immediate problems. 4. Refresher courses, and state-of-the-art techniques for industry personnel.
4. Wealth of faculty expertise and R&D facilities.	Systemic issues (curriculum development; continuing education; external registration for research degrees; library)	5. Industrial orientation for graduating engineers.
5. Library and information services.		6. Continuing education for industry personnel.
6. External registration programmes.		7. Access to textbooks and journals. 8. Advanced degrees for industry personnel.

Table 3. Comparative strengths in industry and institutions.

Industry ahead in:	Institutions ahead in:
Management	Knowledge creation
Productivity	Knowledge transfer
Safety	Rigour of study
Reliability	Communication skills
Cost-consciousness	Research
Interpersonal relations	Publications
Standardization	Conferences
Use of codes and standards	Long-term issues
Time consciousness	
Quality consciousness	
Commercial judgements	
Skills development and application	
Repair and maintenance	

additional focus emerged – academic research (the slogan during this period worldwide was 'Publish or Perish'). In the third decade, the importance of sponsored research and industrial consultancy was recognized (during this period, the slogan became 'Publish and Consult, or Perish'). Over the past six years or so, since the announcement in India of the new economic and industrial policies, issues relating to intellectual property rights (IPR) and the necessity for innovation in technology development have been acknowledged. The national slogan has thus become: 'Patent, Publish and Prosper'.

Sponsored research and development

A Centre for Industrial Consulting and Sponsored Research (ICSR) was established at IIT Madras in 1973, with the specific objective of establishing liaison with industry and promoting cooperation. Most of the sponsored research and development is supported by government agencies and departments.[2] The principal aims of the sponsored research are to generate new knowledge, to develop new technology and to create new products.

Industrial consultancy

Industrial consultancy is essentially supported by various industries to solve specific short-term and medium-term problems. Three types of consultancy are identified:

- Institutional consultancy, which involves the use of faculty expertise and institute facilities for the execution of specific assignments.
- Retainer consultancy, which involves the retention of institute faculty as expert consultants for advice or guidance for a specified duration.
- Research-based industrial consultancy: this classification has been recently introduced to cover industrial assignments which involve a considerable research component; typically, the project duration varies from 6 months to 3 years.

Table 4. Comparative characteristics of university and industry.

	University	Industry
1. Values	Altruistic, scientific	Business-oriented, commercial
2. Activity	Generation and dissemination of knowledge and ideas	Application of knowledge for economic gain
3. Objective	Excellence in academic activities	Customer satisfaction, profit
4. Role	Academic philosophy requires keeping up with theory and applications	Corporate philosophy involves new design and manufacturing processes, innovations, software development
5. Motivation for learning	Knowledge for its own sake; continuous learning to upgrade knowledge	Need-based; learning as necessary
6. Horizon	Long-term	Short-term
7. Output	Academic degrees, publications, patents	Cost-effective quality products and processes
8. Openness	Keen to publish results expeditiously	Keen to keep know-how secret
9. Attitude	'Holier than thou'	'Out here in the real world'
10. Process of human resource development	Education: open-ended process leading to the development of the mind; involves inputs in cognitive and affective domains	Training: specific goal is to impart technical skills; involves inputs in the psychomotor domain

Institutional partnerships

Special bilateral collaborative arrangements have been designed to institutionalize partnerships with industry, provide a sharp focus for projects, and ensure relevance and utility by identifying users as monitors. Efforts have also been made to simplify and streamline procedures in the selection, implementation and monitoring of projects. These include, for example: collaboration with the Indian Space Research Organisation (ISRO), through the ISRO-IIT(M) cell; and with the Indira Gandhi Centre for Atomic Research (IGCAR).

In addition, several memoranda of understanding have been signed both with government agencies and with industrial firms.

The Industrial Associateship Scheme

IIT Madras introduced an Industrial Associateship Scheme in 1987 with a view to strengthening the linkages with small, medium and large industries in a well defined manner. For an annual fee (which differs according to the size of the firm), the Industrial Associates have various facilities and services available to them: library and information services; an annual convention; discounts in registration fees for conferences and workshops; and special programmes catering to the requirements of specific industries or groups of industries. The special programmes include Technology Appreciation Programmes, providing state-of-art information on frontier areas of technology (eg Expert Systems, Advances in Manufacturing, Fibre Optics, Reliability Engineering); Technology Requirements Programmes, to identify industry's needs and assist in the formulation of projects; Technology Assessment Programmes; and Technology Watch Programmes.

Institute–CII partnership

IIT Madras and the Confederation of Indian Industry (CII) have enjoyed a close and symbiotic relationship. The relationship has been developed through the following initiatives: the Industrial Associateship Scheme described above; the introduction of a one-credit course to acquaint students with the challenges and success stories of Indian industry; training capsules for graduate trainees; sponsorship of industry personnel for M.Tech programmes; the establishment of a clearinghouse for interactive activities; part-time courses for industrial professionals; and assistance for the MS (Entrepreneurship) programme.

The growth and profile of IC and SR activities

Figures 1 and 2 show the growth of industrial consultancy (IC) and sponsored research (SR) activities at the Institute over the past decade.[3] In particular, 17 industries from all over the country retained IIT Madras faculty as 'Retainer Consultants' during 1997–98. During this period 29 companies entered into memoranda of understanding agreements under the Research-based Industrial Consultancy programme. As far as sponsored R&D is concerned, 58 new projects were taken up in 1997–98.

Figure 3 shows the distribution of IC and SR activities (in terms of funding support) among the different classifications of industrial consultancy, and among the different organizations sponsoring R&D at the Institute.

Technology Development Missions

The Planning Commission of the Indian government, recognizing the potential of the faculty, expertise and infrastructure facilities at the different Indian Institutes of Technology and at the Indian Institute of Science (IISc), Bangalore, for undertaking commercially exploitable technology development, mooted the idea of Technology Development Missions (TDMs), incorporating close partnership and collaboration with industry.

The following seven areas were identified for TDMs: Food Processing Engineering; Integrated Design and Competitive Manufacturing; Photonic Devices and Technologies; Energy Efficient Technologies and Devices; Communication, Networking and Intelligent Automation; New

Table 5. Comparison of university and industry R&D.

University R&D	Industry R&D
Essentially long-term.	Essentially short-term.
Carried out by graduate students under the guidance of faculty supervisors, with the objective of fulfilling degree requirements.	Carried out by professional personnel with the objective of satisfying customer needs.
Maintaining continuity is more difficult.	Continuity is maintained in proportion to industry goals.
Output is more in terms of research papers.	Output is more in terms of products and processes, and patents.
Research is detailed and in-depth.	Scope of solution is determined by the extent of need.

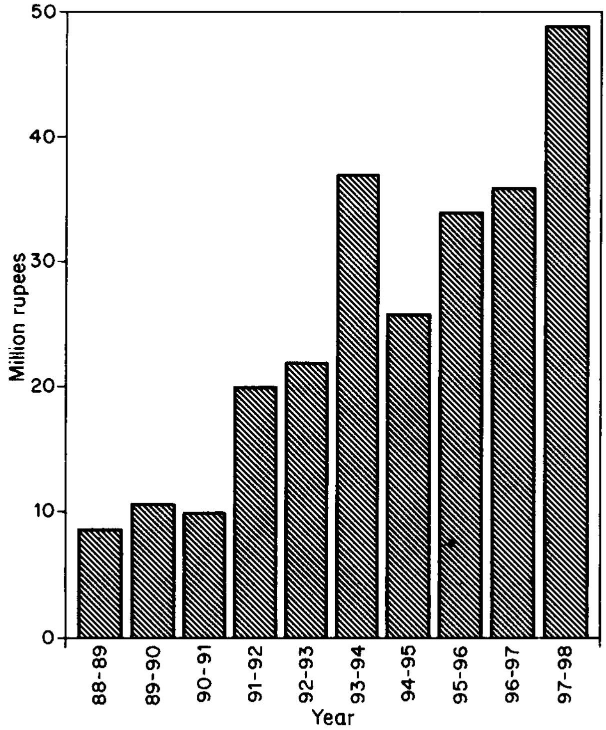

Figure 1. Growth of consultancy activities at IIT Madras over the past decade.

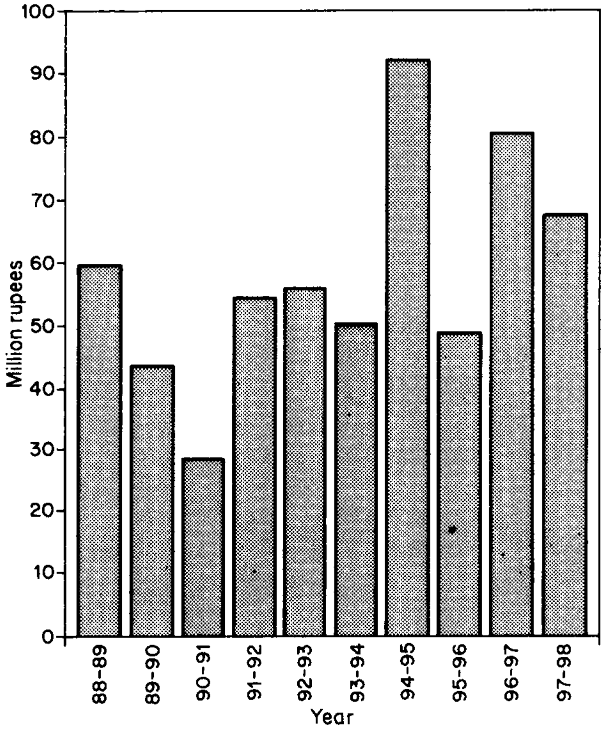

Figure 2. Growth of sponsored research activities at IIT Madras over the past decade.

Materials; and Genetic Engineering and Biotechnology.

The active partnership and involvement of industry were to be essential ingredients of these Missions. A total of 25% of the value of the project should be forthcoming from industry, 15% in kind and 10% in cash. IIT Madras has been responsible, as a Principal Coordinator, for the Energy Efficient Technologies and Devices and the New Materials TDMs. In the Energy Efficient Technologies and Devices Mission, three sub-topics have been identified: Atmospheric Circulating Fluidized Bed Boiler for Industrial Application; High Temperature Industrial Heat Pumps; and Fuel Efficient, Low Emission, Multi-fuel IC Engines. For New Materials, the following sub-topics have been identified: Polymers and Polymer Composites; Advanced Ceramics, Powders and Sensors; Ceramic Matrix Composites; Development of Metal Matrix Composites; and Magnetic Materials.

It is heartening to note that industry has come forward in full measure to support these Missions and the partnerships have resulted in new products, new processes, patents and publications. It is hoped that on successful completion of the several projects under the seven TDMs in about a year or so, a new set of TDMs will be defined in emerging areas to promote innovative research and to make Indian industry globally competitive.

Benefits of collaboration

The major benefits from cooperation with industry that have been experienced by the Institute are: support for infrastructure development, including equipment and instrumentation; additional manpower in the form of Project Associates; contributions to overheads, including maintenance, repair, services, contingencies, etc; projects with a practical orientation for students and research scholars; exposure of our faculty and students to the world of industry.

For its part, the benefits to industry are: the opportunity to use faculty expertise and the infrastructural facilities of the Institute for solving problems of relevance and for the development of processes and products with the potential for commercialization; access to the facilities and expertise of the Institute; and to an extent the students and research scholars of the Institute serve as 'virtual' employees for industry.

Continuing education activities

IIT Madras has a Centre for Continuing Education which facilitates interaction between Institute faculty and firms to identify and match industry needs and faculty expertise. Approximately 40 self-supporting continuing education programmes for industry professionals are held each year. Some of the programmes are also delivered on-site to firms.

The Institute is also considered to be a Resource Centre by the Ministry of Human Resource Development, along with other IITs, for organizing continuing education programmes for the benefit of the faculty members of the other engineering colleges in India. These programmes are held usually during the summer and winter vacation periods.

International collaboration

IIT Madras has been a forerunner in various Indo–US collaborative projects over the years. Since the Indo–German collaboration through the German Ministry of Economic Cooperation (BMZ) came to a close about 6 years ago, a new phase in bilateral cooperation with Germany began through the German Ministry of Research, Technology, Science and Education (BMBF). Under this Programme, IIT Madras faculty take up R&D collaboration with counterpart professors and scientists in German universities and research establishments. In the first phase seven projects were completed, and in the second and current phase ten projects are in progress. These latter projects were reviewed recently and found to be highly successful in achieving the desired objectives. It is hoped that a third series of projects will be taken up soon. The Volkswagen Foundation of Germany has also sponsored six projects involving IIT Madras in the recent past.

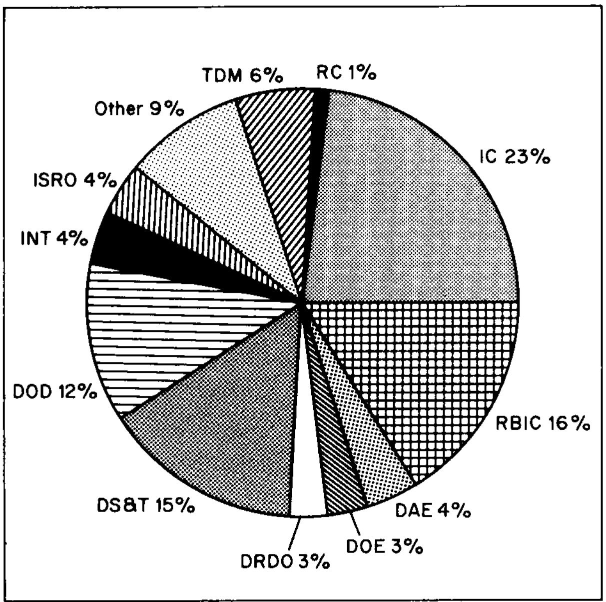

Figure 3. Distribution of funding support for consultancy and sponsored research at IIT Madras.
Key: Consultancy: IC – institutional consultancy; RC – retainer consultancy; RBIC – research-based industrial consultancy. Sponsored research: DAE- Dept of Atomic Energy; DOE – Dept of Electronics; DST – Dept of Science and Technology; DOD – Department of Ocean Development; DRDO – Defence Research and Development Organization; ISRO – Indian Space Research Organization; TDM – Technology Development Mission; INT – international. 'Other' includes, among others, the Dept of Biotechnology and the Aeronautics R&D Board.

Patents

As pointed out earlier, the importance of patents has been recognized and wherever possible patents are applied for. The total number applied for by the Institute is 125; many of them have been commercialized, and some have received Invention Promotion Awards by the National R&D Corporation.

Concluding remarks

As stakeholders in the Indian engineering education system, students and employers are increasingly demanding relevance and pragmatism. The university, as the intermediary, has an important role to play in this venture, and faculty must develop an appreciation of engineering practice. Universities too must learn to earn revenue through the services which they can provide – otherwise they will always be tied to the apron strings of government.

Industrial personnel cannot acquire instant knowledge, any more than academics can acquire instant experience. We need bridges between engineering in the university and technology in industry, built by researchers and educators with commitment. We need policy initiatives in India by both industry and universities to create interfaces to facilitate interaction.

Notes and references

[1] L.S. Chandrakant, Rao K. Seetharama, A. Ramakrishnan, and R. Natarajan, 'Indian industry perceptions of the undergraduate degree curricular offerings', *Journal of Scientific and Industrial Research*, Vol 53, March 1994, pp 210–225.
[2] These included: the Aeronautics R&D Board; the All India Council for Technical Education; the Council of Scientific and Industrial Research; the Defence R&D Organization; the Department of Atomic Energy; the Department of Electronics; the Department of Ocean Development; the Department of Science and Technology; the Department of Telecommunications; the Indian Space Research Organization; the Ministry of Human Resource Development; and the Ministry of Non-Conventional Energy Sources.
[3] The following are examples of sponsored research projects and industrial consultancy projects covering 13 departments of IIT Madras. They indicate the scope of coverage current interactive activities. *Sponsored projects*: studies on shock

wave propagation in gas particle mixtures; development of blood flow visualization techniques to analyse haemorrheological changes in capillaries in health and diseases; design and development of radially pulsed liquid extraction column; novel low-temperature synthesis and structure of new polychalcogenide compounds; appropriate technology for rural housing; knowledge-based computer systems – fifth generation computer systems; development of micro-machined smart sensors for mechanical and biomedical applications; development of a decision-support system for cell formation in group technology; transit analysis of queuing and related systems; pressurized fluidized bed combustion of low-grade coal; fundamental studies in superplasticity and high-temperature creep; sea trial of 150 kW wave energy device; development of materials for hydrogen storage; applied biotechnology for industrial products; studies on jute fibre reinforced composites. *Consultancy projects*: studies on nozzle flow separation; electro-hydraulic servo drive system for multi-barrel rocket launcher; development of test fluid for carburettors; synthesis of pharmaceutical intermediates and products; investigations of fire-affected buildings and recommendation of restoration measures; development of a neuron-based distributed control SCADA system; fuzzy-logic-based self-start for induction motor drives; development of software for life-cycle estimation; microprocessor-based leak detector for automotive water pumps; weld failure analysis of chemical reactor vessels; analysis of design of berths and wharves; stereo microscope optics design; design of FRP blades for cooling towers.

[4] Examples of such activities are: the corDECT Wireless in Local Loop project, in collaboration with Analog Devices of the USA for developing a cost-effective method to provide voice and data connectivity in urban as well as rural areas; NovaSwitch 2400 and NovaSwitch 12000 – a high-performance Ethernet Switch; NSF-Funded Pressurized Fluidized Bed Combustion Facility; Advanced Technology for Combustion of Biomass (Indo–Swedish Project); Performance of Galvanized Reinforcements in Tropical Marine Environment (for the International Lead Zinc Research Organization); Biological Production of Chiral Compounds for Optically-Active Pharmaceuticals (Indo–Korean Project); Design and Control of Intermittent Water Supply Systems (Indo–European Project); Development of Foot Model and Pressure Monitoring System (Indo–Netherlands Project); (i) Redox Mechanism in High-Temperature Superconductors (Indo–French Project).