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EDITORIAL

The science of engineering

Attending good lectures is one of the most painless, and probably most pleasant, ways of acquiring information in science. At a recent meeting of the Indian Academy of Sciences, I was a fortunate spectator at a marvellous presentation of a metallurgist's view of quasicrystals, the problems of filling space with atoms of differing sizes and the connections between the concerns of materials science and the apparently disparate fields of physics, chemistry, biology, mathematics and metallurgy. The speaker, a colleague of mine, S. Ranganathan, began with Johannes Kepler's musings on the shapes of snowflakes, moved to Linus Pauling's classic determination of the structures of intermetallic compounds, discussed the early ideas of J. D. Bernal and Alan Mackay, described Roger Penrose's, now famous approach to the tiling problem, before presenting his own work, and that of colleagues, on the problems of five-fold symmetry and quasicrystals. On the way, the speaker alluded to Dmitri Mendeleev and his periodic table, but provided a view of materials that seemed to rely on the tenets of metallurgy, with the inevitable invocation of the name of William Hume-Rothery. In the enthusiastic discussion that followed physicists, chemists and biologists seemed to identify themselves with the problems of filling space with atoms; geometry, chemistry and nature seemed to be working in concert. At the tea, to which the audience adjourned, I encountered another colleague, a professed solid state chemist who remarked: 'The metallurgists' approach to the problem of quasicrystals and interatomic interactions is intuitive and empirical.' He seemed to imply that physicists (and presumably the more rigorously minded chemists) would address the same issue with greater theoretical finesse. In thinking about this rather casual, offhand comment, I came to an obvious conclusion; disciplines and their contours have a long evolutionary history, which shapes the thinking of their practitioners. But, more pertinently, the speaker who belongs to a Department of Metallurgy is categorized in our surroundings as an engineer, while the vast majority of the audience consisted of those who would label themselves as 'pure' scientists. Metallurgy, of course, has been traditionally considered as an engineering discipline; metallurgical engineers have, in the past, been much sought-after by heavy industry, particularly those dealing with steel and aluminium. Metallurgy also has a hoary history as an empirical science; the Iron Pillar in Delhi providing a spectacular example of the state of the subject nearly 1600 years ago in India (Balasubramaniam, R., *Curr. Sci.*, 2002, **82**, 1357). But, metallurgy's face has been transformed by the remarkable growth of materials science, a field that lies at the confluence of chemistry, physics and metallurgy. Biology too, threatens to provide insights into the construction of the materials of the future. The obvious applications of new materials lie in every area of engineering and will undoubtedly catalyse the next technological revolution.

Science and engineering, upon careful reflection, appear to be seamlessly connected; but, in reality, in our institutions, they are sharply divided. In the Indian Institutes of Technology (IITs), the flagship engineering institutions in India, the science departments, mathematics, physics and chemistry, are intended to provide basic background in these disciplines for a large undergraduate population, while maintaining research programs, catering to prospective Ph D students. The engineering departments have very large teaching commitments, with generally fewer research students. At the Indian Institute of Science (IISc), the absence of an undergraduate program was presumably intended to enhance the focus of research in both science and engineering. Indeed, when students first entered IISc in 1911, two years after its founding, they were greeted by two departments, representing distinct streams, General and Applied Chemistry and Electro-Technics (renamed two years later as Electrical Technology). But, as the institution grew in size, the perceptions about science and engineering seemed to diverge; while, science departments appeared to have research as a dominant commitment, engineering sections acquired a greater role in teaching, training and industrial consultancy. Curiously, when departments in different areas of engineering were grouped for administrative convenience, the resultant groups were christened as Divisions of Mechanical and Electrical Sciences. The term 'sciences' appeared to be a larger umbrella, capable of accommodating departments in diverse (but at times, perilously close) disciplines of engineering. Undoubtedly, even the most thoughtful of academic administrators must have difficulties in resolving internal conflicts about the terms science and engineering.

Simply, the common (and admittedly, prejudiced) view may be stated thus: 'Academic scientists do research, publish papers and train more scientists; Academic engineers train other engineers, who do useful work and sometimes do apparently useful work themselves, through their interaction with industry and government'. This stereotypical definition is changing, as more scientists, particularly chemists and biologists, move towards closer interaction with industry. But, one message seems clear; research appears to be an activity of limited import on the academic engineering scene. There are, of course, many celebrated researchers in the engineering departments of our high profile institutions, many of whom are indeed scientists of great distinction; their work often closely overlapping with the interests of colleagues in allied areas of science. There are some subjects which run as a cementing thread across the disciplines; fluid dynamics, for example, can bind researchers of distinctly different persuasions.

In trying to find a clear definition of *engineers* and *engineering*, I turned to Eugene Garfield (*Essays of an Information Scientist*, Vol. 12, pp. 304–309, 1974–1976), who in the early days of scientometric analysis, had indeed struggled to define these terms. He points out that Webster's dictionary yields the following definition of engineering: '. . . the science by which the properties of matter and the sources of energy are made useful to man in structures, machines and products'. Garfield then, ruefully, adds that 'Leonardo DaVinci would have readily accepted this definition as descriptive of his main interests and employment'. He inevitably, moves to identifying engineers and their research interests by examining publications and citations. Using data for 1969, Garfield compiled two lists: A set of 50 journals, which were most often cited by a group of engineering journals and a list of 50 titles, which most often cited his chosen journal group. Looking through these lists even I recognized some perennial favourites of academic engineers; *J. Fluid Mechanics*, *J. Acoustical Soc. America*, *J. Applied Mechanics*, *Chemical Engineering Science*, *AICHE Journal* and as many as 12 titles of the Institute of Electrical and Electronics Engineers (IEEE). There were, of course, several science journals common to these lists; *J. American Chemical Society*, *Physical Review* and *J. Applied Physics* appeared, an indicator that engineering and science are inextricably linked. Over 30 years later academically successful engineers might still like to publish their results in many of the journals on Garfield's lists. But, it does seem that in the academic engineering departments in India, publication of research does not seem to be a critically important activity. To a great extent, this situation is a consequence of the diminishing quantity and deteriorating quality of students, who choose to obtain research degrees in engineering. Ironically, while there is a mad scramble to enter engineering courses after high school, students leave academia with undergraduate degrees, often deserting the discipline in which they have been trained. The prospects of well-paid employment in the areas of management, software and 'information technology' prove irresistably seductive. This state of affairs appears to have led to a widely held perception in India, that research may not be a central activity of an academic engineering department.

The boundaries between science and engineering are sometimes sharply drawn. In reporting on a millennial symposium of the National Academy of Engineering USA, celebrating the greatest engineering achievements of the 20th century, *Physics Today* (May 2000, pp. 48–49) charged the engineers with neglecting to highlight the fact that many of the most spectacular technological advances had their roots firmly grounded in physics. Electrification topped the engineers list; *Physics Today* was quick to remind its readers that the roll call of honour would be led by the physicists Michael Faraday, James Clerk Maxwell, Hans Christian Oersted, Alessandro Volta, Georg Simon Ohm, Joseph Henry and Nikola Tesla. Further down the list was electronics, and here the physicists claimed John Bardeen, Walter Brattain and William Shockley, inventors of the transistor and more recently, Jack Kilby, who developed the integrated chip. In arguing about the distribution of credit for technological advances, both engineers and scientists skate on thin ice. One cannot do without the other. Scientists in all areas, physics, chemistry, biology, geology amongst them, rely on precision engineering to produce the instruments that advance their fields. Engineers play a critical role in transforming basic advances in science into the technologies of daily use. Several years ago, on the threshold of the digital revolution, W. O. Baker considered the issue of 'concurrency on the future of science and engineering' and its portents for the future (*The Bridge*, National Academy of Engineering USA, 1986, **16**, 19). In addressing the future possibility of a 'non-traditional juncture of science and engineering', Baker advanced the cause of reforming science and engineering education. Unfortunately, in our environment, instead of promoting a coming together of the disciplines, our pattern of education has tended to insulate subjects and departments.

Innovative technology, which politicians and policy-makers clamour for, can only be born by a fusion of good science and engineering. The rapidly emerging fields of nanotechnology and biotechnology may be advanced only by a 'broad coalition' of scientists and engineers. For this to happen there must be a greater appreciation of science in our departments of engineering, while students of science must be aware of the enormous gulf that engineers bridge, when they transform a scientific advance into a technological success. This coalition must be spearheaded by interpreters who speak both languages. I suspect that it might be easy to find the 'scientists' amongst engineers, who can indeed forge such a coalition, the need for which is being more widely felt in the best of our institutions. The science of engineering requires greater exposure. The lecture which catalysed this essay is a stellar example.

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