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EDITORIAL

Tools as Drivers of Science

In the mid 1970s, when I began my career as an observer of science and scientists, academic laboratories in India were poorly equipped. Instrumentation was scarce and computers, where available, were monstrous entities hidden away in air-conditioned seclusion. Few laboratories and even fewer offices sported air-conditioners. The capricious power supply was not supplemented by standby generators. Power cuts, frequent and unpredictable, provided a justifiable reason to adjourn to canteens. Physicists often made their measurements with home built devices and engineering departments appeared filled with large and impressive machinery, conveying a sense of great utility. Relatively few theoreticians stalked the corridors of academic physics and engineering departments. 'Simulation' was a word that had not yet entered the lexicon in our institutions. Chemistry appeared to require little by way of sophistication; laboratories sported glassware of various shapes and sizes, with heating and stirring being the most common operations. Mixture separation relied on the robust methods of classical chromatography, which taught students the virtues of experimental skill and patience. Analysis was dependent on a couple of sturdy and over-used infrared and UV–Visible spectrometers, housed in centralised instrumentation facilities. Nuclear magnetic resonance (NMR) spectrometers were rare; available only in privileged institutions and often declared as 'national facilities'. X-ray diffractometers were yet to make a significant appearance. 'Structural biology' was a term that had not surfaced. Electron impact mass spectrometers were an esoteric and distant tool for most chemists in India. Biology appeared to demand even less by way of instrumentation. Light microscopes and refrigerated centrifuges, supplemented by a carefully preserved spectrophotometer, seemed to serve the needs of biochemistry and microbiology, while botany and zoology were even less demanding subjects. Ice flakers were largely unknown and crushed ice was simply obtained by able bodied students pounding a large block of ice, enclosed in a sack, to pieces. The ends of physical exercise and the need to vent frustration were both served in this essential operation, which most research students of chemistry and biology quickly learned to master. Liquid nitrogen was scarce; liquid helium truly rare leaving physicists content with temperatures commonly attainable. Biology was poised on the cusp of change. The term 'molecular biology' was beginning to be heard in seminar rooms. DNA was on its way to becoming an object of reverence. The emerging methods of recombinant DNA technology were mentioned with awe in corridors and 'genetic engineering' rose with amazing rapidity to become a much sought after discipline amongst new students entering research. 'Biotechnology' promised much and traditional biology courses were quickly renamed, hoping to attract students to a subject that held out hope for a bright future.

By the early 1980s, the organisational structure of the departments of government, charged with supporting academic research, had undergone major transformation. Individual investigator driven grants and departmental support programs became available, even as new techniques began to gain ground. The drive towards organised research gained momentum and equipment began to slowly appear in many institutions. Money was scarce and the battle to obtain equipment could be long and wearying; maintenance a difficult and tiring task. Foreign suppliers had a negligible presence in India and local agents lacked both the expertise and the tools with which to rectify malfunctioning equipment. Foreign exchange, in the days before the economic liberalisation, was not always readily released for major imports. The winds of change were felt in the late 1980s as the personal computer revolution gained momentum, driven by a sudden loosening of import restrictions. The effects of an improving economic situation were evident by the late 1990s as science funding began to show an upward trend. The growth in research grants and support for establishment of major research facilities in academic institutions has been pronounced in the last decade, with the promise of increased research spending in the 12th Five Year Plan, whose formal launch is anticipated very soon. The major institutions and centres of research in India present an appearance today that is a far cry from the scene that confronted observers twenty years ago. Laboratory instrumentation has grown dramatically in numbers and in sophistication. The many new institutions that are being created find it easier to acquire equipment than to recruit faculty. New centres in old institutions (and mine is a prime example) are significantly better equipped than old traditional departments. In the burgeoning number of new institutions that have been created, equipment has often arrived before laboratory spaces are available. Long delays in installation and use are not uncommon. Researchers on the verge of an independent scientific career, fresh from postdoctoral stints in foreign laboratories now set about attempting to replicate experimental facilities that they are familiar with. The sophistication of the faculties created does not always match the nature of the research envisaged. Centralised facilities of a very high degree of complexity of operation and maintenance are created with a limited assessment of the long term needs of manpower and supporting infrastructure to ensure efficient functioning. Despite concerns raised by the rapid expansion of research facilities in many institutions, there is little doubt that the past decade of steadily growing science funding has enhanced the quality and quantity of scientific output across the country. While some analysts worry that the rate of growth of scientific research in India does not match that in countries like China, which gallop along at a fearful pace, unbridled expansion undoubtedly creates new problems for the scientific community to address.

Is there a downside to the march of science driven dominantly by new instruments of measurement and analysis. Is science, as Freeman Dyson asked years ago, 'being driven by new technology rather than by new concepts'? Dyson returns to this question in a commentary that asks: 'Is science mostly driven by ideas or by tools?' (Dyson, F. J., *Science*, 2012, **338**, 1426). He begins, predictably, with Thomas Kuhn's analysis of the development of science, *The Structure of Scientific Revolutions*, which appeared in 1962 and was greatly influenced by the upheaval in physics in the early years of the 20th century. Kuhn introduced into the vocabulary of science the word 'paradigm', which is more misused than understood. The romantic view of science owes much to Kuhn. Revolutions happen, 'a discontinuous shift from one paradigm to another' when, in Dyson's words, 'new ideas explode with a barrage of new insights and new questions that push old ideas into oblivion'. Relativity and quantum mechanics were 'new paradigms created out of abstract ideas'. This physics centric view of science may ignore revolutions that happened over long periods of time, imperceptibly changing the foundations of disciplines. The cataloguers and classifiers who were the drivers of change in the 19th century, Mendeleev in chemistry and Darwin in biology were responsible for gradual shifts in ideas that dominated their disciplines. Atomic theory subversively entered chemistry, establishing itself as opponents gradually departed from the fray. In attempting to address the question posed in the title of his commentary, Dyson draws attention to a 1997 book, *Image and Logic*, by Peter Galison which emphasises the key role of tools in driving science. Dyson notes that 'Galisonian science' always existed, but was dismissed 'with the epithet normal' by Kuhn. He points out that 'the tools of steam engine technology came first, before the ideas of thermodynamics; the tools of telegraphy and telephony came first, before the ideas of information theory'. Dyson provides a unique insight into the state of science in the middle of the 20th century, when 'the world of physics was sharply split into Kuhnian and Galisonian programs'. He is well positioned to pass judgement: 'The old heroes of the pre-war revolutions were pursuing private dreams of Kuhnian revolutions still to come. Einstein dreamed of a unified field theory. Heisenberg and Schrödinger and Dirac each had a dream based on equations rather than on experiments. Each of them believed that progress in physics could only come through revolutionary new ideas. Each of them dreamed of repeating the triumphs of the 1920s. Meanwhile, the younger generation was using the new tools generated by military technology to push science ahead in Galisonian style.' He cites examples: Martin Ryle and radioastronomy, Willis Lamb and the hydrogen atom's fine structure, Maurice Wilkins and Rosalind Franklin's X-ray photographs of DNA fibres, which led to the double helix and Melvin Calvin's use of radioactive tracers and paper chromatography to probe photosynthesis. He concludes: 'Four new tools created four new sciences. Ten years after World War II ended, Galisonian science was roaring ahead while Kuhnian dreams had faded. And so it continued for the rest of the 20th century.' Dyson's focus is physics and his assessment at the end of the first decade of the new century is revealing: 'We are standing now as we stood in the 1950s, between a Kuhnian dream of sudden illumination and a Galisonian reality of laborious exploring…. The balance today is more even than it was in the 1950s.'

If we escape from a physics centric view of science one might conclude that in disciplines like biology or chemistry a Galisonian world view prevails. Biological sciences today are driven, more than ever before, by tools and technologies. As data of diverse kinds pour in, the tasks of interpretation seem daunting. In a companion commentary, Sydney Brenner provides a characteristically provocative view of biology, arguing that 'the whole of biology must be rooted in DNA, and our task is still to discover how these DNA sequences arose in evolution and how they are interpreted to build the diversity of the living world. Physics was once called natural philosophy; perhaps we should call biology "natural engineering" ' (*Science*, 2012, **338**, 1427). Biological researchers today may be divided into two camps; one using a wide range of tools to address specific problems while the other uses a limited range of extraordinarily powerful tools to generate a bewildering mass of data. The tensions between the advocates of what is euphemistically called 'hypothesis driven research' and the practitioners of technologically driven 'data intensive research' are evident. But both camps are adherents of Galisonian science; that is the reality of biology. As Indian laboratories in academic institutions accumulate the increasingly expensive tools and technologies of science, it may be important to remember that tools are only as good as the workmen who handle them.

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