The real and metaphorical chemistry of the Nobel Prizes

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Doing first-rate science and winning or missing a Nobel Prize for it, is a topic that is of much interest to scientists, non-scientists and fiction writers[1]. There are other highly prestigious prizes – the Fields Medal in mathematics, the Turing Award in computing, the Marconi Prize in communication technology, the recently launched Fundamental Physics Prize, etc. However, the Nobel Prizes in the sciences probably because of their long history rather than the monetary value, as yet remain unparalleled in terms of visibility, mystique and the power to mould public perception of science.

According to a recent newspaper report, about 90% of Indian scientists and institution heads who are invited to nominate names for the Nobel Prize simply do not respond to the invite[2]. Could this then be the explanation why India has failed to produce a single Nobel laureate in physics, chemistry and biology after C. V. Raman? To assuage our national pride it may be tempting to accept this as part of the explanation, but that would be incorrect.

Letting invites 'rot' by not responding is one of the examples of the non-professionalism of people in power in our scientific establishments, but does not explain the depressingly sorry state of Indian science. Great discoveries do not happen by fluke. While serendipity may play a role, important discoveries have always been and will continue to be based on good science and hard work.

The Nobel Prizes in the sciences are given for break through discoveries rather than sustained, voluminous contributions. The lack of enough high-quality scientific research resulting in breakthrough discoveries is the only reason for so few Nobel laureates from countries like China, India and many others. In short, in India we have produced little good science in a sustained manner. In spite of adequate funding and innumerable research institutes – old and new, why this should be the state of Indian science was discussed in a recent commentary in this journal[3].

The purpose of this commentary is different and twofold. First, as the title indicates, by analysing a few of the recent Nobel Prizes, mainly in chemistry, it aims to show the kind of changes that are becoming important for producing good science. Secondly, it emphasizes the basic: high-quality science with a focus on improved science education and innovation must be the twin goals for Indian science. Whether or not this leads to a Nobel Prize in the long run is of secondary importance.

As most practising scientists know, all good science does not result in breakthrough, Nobel Prize-winning discoveries; in fact, only a small fraction does. Discoveries that significantly influence the thinking of other scientists, open up new areas of research, and those which may have peaceful applications, are usually the ones that win Nobel Prizes. In short, to produce high-quality science with the potential of break through discoveries, the right 'metaphorical chemistry' has to be struck between creative imagination and the rigours of painstaking verification, i.e. the methodology of experimental science.

An essential requirement for creative imagination is an adventurous approach, the willingness to search for problems that usually lie at the intersections of rigidly defined disciplines and sub-disciplines. Scientific discoveries that have far-reaching implications both in terms of explanatory power and potential utility do tend to cut across disciplines. They increasingly tend not to belong to rigidly defined areas of physics, chemistry and biology.

Two examples show the pivotal role played by chemistry in Nobel Prize-winning discoveries not in chemistry, but in physics and biology. These are the Nobel awards in physics for high-temperature cuprate superconductor and in medicine for the discovery of the role of nitric oxide in biological signalling.

Chemists in the last 60 years made a huge number of materials, determined their structures, but left the job of measuring electrical and magnetic properties of such materials largely to the physicists. This is evident from the fact that although magnesium diboride was made and structurally characterized in the 1950s, its high-temperature superconducting property was discovered more than 50 years later; long after the discovery of cuprate superconductors. In the words of Roald Hoffman a chemist, Muller and Bednorz, the discoverers of cuprate superconductors and *physics* Nobel laureates are 'our own'; the 'awards for cuprate superconductors…do move in our (*chemists*) direction' (italics added)[4].

The gas nitric oxide and its compounds have been studied by chemists for more than 100 years. However, the critical role of nitric oxide in biological signalling processes was discovered by biologists only in the late 20th century. Nitric oxide was called the molecule of the year in 1992 and the discoverers of its biological role shared the Nobel Prize for medicine in 1998. There were thousands of publications on nitric oxide in the chemical journals before, and predictably a lot more after the award. Not surprisingly, there is little documented evidence to show that before the award chemists made any serious effort to study the biological role of nitric oxide.

These examples, and there are many others, show that discoveries where chemistry may play a critical role, increasingly do not originate from research that belongs exclusively to 'chemistry' defined in the old-fashioned way. Chemistry has been called the 'central science' precisely because of its frequent seamless overlap with physics and biology. Chemists as a community seem to have ignored this fact and in the process allowed exciting research opportunities to slip out.

Even within chemistry the rigid and narrow approach has come in the way of quick recognition of major discoveries. A significant number of the recent chemistry Nobel Prizes cut across traditional sub-disciplines such as inorganic, organic, physical, etc. In this century, out of the 13 Nobel Prizes in chemistry, as many as 4 have been awarded for work related to catalysis, an interdisciplinary area of much industrial relevance.

Three of the four prizes are for the applications of transition metal complexes as catalysts in solution, where the pioneering papers were published in the late sixties or early seventies. However, it took four more decades for the practitioners belonging to other sub-disciplines of chemistry to take serious note of these discoveries, and collectively establish and accept their enormous scope and utilities.

Each of the four award-winning catalysis work also had a definite application stance. It either dealt with a critical 'know how' question, or addressed the 'know why' behind an important 'know how'. It is no wonder that the three awards – asymmetric catalysis in 2001, metathesis in 2005 and palladium catalysed cross-coupling in 2010 – have all found major applications in chemical and pharmaceutical industries. In all the three cases, one of the Nobel laureates was from an industry. The fourth award to Gerhard Ertl in 2007, a physical chemist, was for providing answers to 'know why' questions of enormous technological relevance, using the tools of surface science.

These examples are relevant for two reasons. First, they underline the synergy that exists between high-quality academic research and practical demonstrable peaceful applications based on such research. This relationship is, to use fashionable terminology, what science-driven innovation is all about. Second, they also show how fundamental discoveries in science are becoming increasingly innovation-centred.

The creative imagination of the metaphorical chemistry mentioned earlier must therefore not only transcend the boundaries of disciplines and sub-disciplines, but also that of 'know why' and 'know how'. It is worth pointing out that science-based innovations, big and small, have always been critically dependent on asking the right 'know how' and 'know why' questions and finding the right metaphorical chemistry between them.

Good science requires adequate funding, scientists who have their feet firmly on the ground but of adventurous spirit, and most importantly, good students. Since funding and other resources are limited in India compared to the West, the only practical way out is to pool resources together. In other words, meaningful collaborative research among scientists must be the priority of the day. This requires talented solo players to develop their skill in metaphorical chemistry of another kind – proactive collaborations with others who can contribute.

Students with good understanding of the fundamentals are vital for ambitious research. While this requires improvements and changes in science education at all levels, a small beginning could be made by focusing on students about to embark on doctoral programmes. The fact that even today formal offering of courses in catalysis, environmental chemistry, smart materials, etc. do not exist in most of our educational institutions, speaks volumes about the importance given to teaching.

As research funds in India are almost exclusively sourced from the Government, any request for increase in funding must be accompanied by credible demonstration of innovation or excellence[5]. All concerned citizens have good reasons to be wary of big research projects, the promises of instant innovations, and introduction of technologies that pay no attention to the socio-economic realities. The indiscriminate use of the tag 'technology' might have helped some scientists to attract substantial funds, but for how long they would continue to enjoy societal trust is another question.

Global history of the last 150 years clearly shows that improvement in the quality of science and its ability to deliver societal benefits go hand in hand. It also shows that good science almost invariably comes from small science, away from the spotlight. Excellence in research only comes when backed with inspired science education in the classrooms. Pooling resources together at the research level and improving quality of education at least in the reasonably well-endowed institutes in India do not require bureaucratic interventions. The scientists themselves, many of whom are chemists and in positions of power, can help bring in good metaphorical chemistry provided there is a serious intent of purpose.

1. Djerassi, C., *Cantor's Dilemma*, Penguin, 1991, pp. 1–23; Djerassi, C. and Hoffmann, R., *Oxygen*, Wiley-VCH, 2001, pp. 1–119.
2. *The Times of India*, 1 January 2014.
3. Verma, R. K., *Curr. Sci.*, 2013, **105**, 1339–1341.
4. Hoffman, R., *Angew. Chem.*, *Int. Ed. Engl.*, 2012, **51**, 1734–1735.
5. Science Advisory Council to the Prime Minister, *Curr. Sci.*, 2013, **105**, 1329.

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