The grand challenge and ethics of the 'central science'

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Chemistry, one of the main branches of natural science, has been called the 'central science'. Whether or not it has 'easily articulated grand challenges', a question posed in *Nature* is an intriguing one[1]. Could it be that 'easy articulation', an advantage enjoyed by physics and biology, may actually mean more of packaging and less of substance? If so, then ethical advocacy of all science and not just chemistry must start with a look at funding of science.

The cost of scientific research and education is borne by society; with those expectations of evidence-based rational thinking that ultimately contribute to the well-being of society. On this count, science over the last decades has been a source of disappointment. The economic orthodoxy of more than three decades and its socio-political impact have taken a heavy toll on the whole framework of rational and ethical thinking. Of the two paymasters of science, government and industry, the former has become the only patron of basic science. The competition between different branches of science for Governmental funds has therefore been intense[2–6].

Starting with the human genome project, grand challenges in science became synonymous with mega projects. To keep the tax-payers happy, a catchy technology tag such as 'bio', or 'nano' had to be added. Till today neither 'bio' nor 'nano' has delivered any significant technology, the benefits of which percolate down to the common man. The hype has turned out to be more about a chase for glory and biotech profit than about societal benefits.

It would be foolish to deny the importance of curiosity-driven as well as oriented basic science in what is euphemistically called the 'ecology of innovation'. However, ignoring the socio-economic contexts and the innumerable gaps between science and technology on the one hand, and technology and innovations on the other, when deliberate, is an indication of questionable collective ethics[5,6]. Big science and mega projects may be 'grand' to those who want mega-funds, but they do not deliver innovations. Many grand discoveries and inventions in science, at least in chemistry, came from small science and a search for practical solutions to specific problems.

In chemistry, inventions and discoveries have frequent spill-overs from one to the other[7,8]. The motive behind many successful inventions was 'how' to find a solution to a specific problem. Once the 'how' question was answered a 'why' question, such as 'why' a particular solution worked while others did not followed. The following three examples showcase the synergistic relationships between landmark discoveries and great inventions.

The pain-killer aspirin was invented by Felix Hoffmann[9] and patented by Bayer. At that time, the pain relieving properties of 'salicin', a component isolated from the willow tree were known, but it had to be taken in large quantities and irritated the stomach. Hoffmann's invention provided solutions to these problems. The invention in short was how to make authentic acetylsalicylic acid, i.e. aspirin. More than 70 years after Hoffmann's invention, Robert Vane discovered the pharmacological link between aspirin and the prostaglandins. He provided the answer to the 'why' question and won a Nobel Prize in medicine. More importantly, the answer also triggered the inventions of a new generation of heart drugs, the so-called ACE inhibitors.

The second example deals with the inventions of several organic polymers in the last century. Two of the largest selling polymers of today, polyethylene and polypropylene, were first reported in a series of patents filed in the 1950s by Karl Ziegler, Gulio Natta, and their co-workers. Natta had also reported the polymerization of acetylene, but in a rather obscure journal, and the material was difficult to characterize and investigate any further. His work was improved upon in the 1970s by Hideki Shirakawa[10] and others. Eventually this led to the discovery of organic polymers that could conduct electricity. Such polymers are now an integral part of the electronics industry. Ziegler and Natta won the Nobel Prize for their inventions and discoveries in 1963, while Shirakawa shared it with two others, a physicist Heeger, and another chemist MacDiarmid in 2000.

The final example is the synthesis of ammonia from nitrogen and hydrogen using a solid catalyst patented by Fritz Haber and Robert Le Rossignol[11] in the early 20th century. The work was sponsored by the German company Badische Anilin and Soda Fabrik (BASF). Carl Bosch turned the invention into a viable technology. His discoveries were related to high-pressure chemical reactions. Gerhardt Ertl revisited the Haber–Bosch process 70 years later, and provided molecular-level explanations for empirical observations. Haber, Bosch and Ertl won the Nobel Prizes in chemistry in 1918, 1931 and 2007 respectively.

Ethical practices of all sciences, not just chemistry, must include the community, the individual, and the social context. Industrial ammonia synthesis and Haber's personal life are particularly instructive from the point of view of the ethics of science. They bring into focus the complexity that arises from the intermingling of collective ethics and personal choices in a given social and historical context. When science is turned into technologies, depending on the purpose for which it is used, it could be immensely beneficial, or devastatingly destructive. As has been said before, science provides a key that opens not just the gates of heaven, but also those of hell. The choice of which one to open is left to mankind. The Haber–Bosch process for ammonia synthesis is an apt example from the world of chemistry.

Much has been written about modern agricultural methods and the Green Revolution[12–14]. In general any technology is a halfway house between heaven and hell, a balance between public good and private incentive, between innovation and profit. Industrial manufacture of ammonia is no different. Without synthetic ammonia, most of which is converted into inorganic fertilizer, more than half of the population of today's world will starve[15]. However, ammonia is also converted to ammonium nitrate – a powerful explosive that is widely used in the mining and armament industries, as well as by terrorists in today's world. The rapid commercialization of the Haber–Bosch process had much to do with Germany's involvement in the First World War (WWI).

The two wars of the last century were the defining moments when many scientists had to make ethical choices. WWI was called the 'chemists' war' because of the large-scale use of high-powered explosives and poison gases. Haber considered it to be his patriotic duty to take part and contribute to the war efforts of his Fatherland. He was a prime mover for the use of poison gas in WWI. He was not alone in his enthusiasm for the war. There were chemists in France and UK, who enthusiastically took part in similar projects[16]. If WWI was a 'chemists' war', the Second World War (WWII) which saw the development of the atom bomb was the 'physicists' war'[17]. Haber the chemist had a choice during WWI, just as many physicists did during the Manhattan project, the development of the hydrogen bomb and the arms race that followed.

Mercifully, during peacetime the ethical choices made by scientists are less sharply defined. Nonetheless, they are not free of ideology or of conflicts of interests. In today's 'post truth' world, both collective ethics and individual choices of scientists, not just chemists, must begin with transparency and truthfulness. Acknowledging that science is not free of ideology, that there may be lack of sufficient evidence in many areas of science, and avoiding actual and potential conflicts of interests both collectively and at a personal level would be a welcome beginning. In so far as chemistry is concerned, the impact of chemicals on public health, environment and sustainability is clearly a matter of great societal concern. They must be of concern to chemists too.

It is a fact that many chemicals damage health and environment, and even kill, just as many chemicals cure illnesses and add to the quality of life. Also, depending on the amount, the same chemicals, and even some elements, can be beneficial or deadly. Everything labelled as 'organic' or 'natural' is often neither and could contain chemicals whose toxicity or long-term effects are not fully known or established. Finally, the most important fact is that neither profit-making companies nor the governments, and not even the regulatory bodies, care much about public health or the environment, unless they are made to do so by the civil society.

Many toxic elements and compounds, both organic and inorganic, come from nature. In the past, when our knowledge was limited and there were no alternatives, some of them were successfully used in medicinal formulations but with harmful side effects. However, once the toxicity or the harmful effect of a substance was established, chemists took a lead to warn the society about the dangers. Zinc white was recommended as a substitute for lead white in paints by chemists as early as Lavoisier's time. This was because the toxicity of lead white was already suspected. In more recent times, once the potential dangers of racemic drugs or chlorofluorocarbons became known, chemists both in academia and industry successfully developed alternatives.

Today a chemist, whether in industry or academia, must tailor and exercise his professional choices keeping these boundaries in mind.

Communicating the enabling essence of chemistry and its expected roles in emerging sustainable technologies to the students of chemistry is of paramount importance. However, such knowledge may well have to be acquired, both for teaching and research, by investing time, energy and effort. This will bring in two positive changes: fewer respectable but mundane publications, along with a heightened awareness and understanding of interdisciplinary areas even within chemistry.

In the context of developing nations, there are other fundamental challenges. The Bhopal tragedy in India was a man-made disaster. The toxicity of methyl isocyanate, the dangers of storing large quantities of it, and the threat of runaway reactions leading to explosions, were all well known at that time. Bhopal was waiting to happen, if not in India, then somewhere else in the developing world around that time[18,19]. It was not a failure of chemists or their science.

The heightened awareness of today's civil society about public health and the contamination of food, water, etc., with potentially toxic chemicals is therefore a welcome change. It is a small but significant step towards sustainability. Chemists must use their specialized knowledge and skill to turn it into an opportunity for engaging in a dialogue with the civil society. 'Business as usual' will only ensure that chemistry ceases to be the 'central science'.

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