Science as an Adventure

Hermann Bondi

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Fig. 1. Hermann Bondi delivering the B.M. Birla Science Centre Distinguished Lecture

Hermann Bondi was born in 1919 to Samuel and Helene Bondi of Austria. He had his education at the Real gymnasium in Vienna. He went on to study at Trinity College, Cambridge. But during World War II he was interned as alien enemy. This gave him the opportunity to work with Thomas Gold and Fred Hoyle on the radar. He became a Fellow of Trinity College in 1943 and in 1947 he married Christine Stockman.

Around 1948 Bondi and Gold and from an independent perspective, Hoyle propounded the Steady State Theory of the universe. While the approach of Bondi and Gold was through a perfect cosmological principle, Fred Hoyle was working with the idea of a field out of which matter would emerge.

Bondi held various positions during his long and interesting career, starting as a temporary Experimental Officer for the Admiralty in 1942 through Assistant Lecturer in Mathematics in Cambridge University in 1945 and Lecturer in

B.G. Sidharth (ed.), *A Century of Ideas,* 13–18.

1948. He was Professor of Mathematics at King's College, London in 1954 and became the Director General of the European Space Research Organization during the period 1967 to 1971. From 1971 to 1977 he was Chief Scientific Advisor to the Ministry of Defence in Britain, then Chief Scientist for the Department of Energy between 1977 to 1980 and Chief Executive of NERC between 1980 to 1984.

This apart he had become a Fellow of the Royal Society in 1959 as also Fellow of the Royal Astronomical Society. He was knighted in 1973.

He received numerous medals and honours and visiting professorships. In 2002 he was given the gold medal of the Royal Astronomical Society. He died in 2005. Bondi has a large number of publications – papers and books to his credit.

He visited the B.M. Birla Science Centre twice and delivered lectures under the Distinguished Lecture series. He spoke about Energy and also the Adventure of Science. The point that Bondi made was that advances in telecommunication would cut costs as well as dependence on fuels. For example one could have teleconferences or work from home on a computer – all this at a fraction of the transport and travel costs. Perhaps this is the shape of things to come. He was a rationalist, which means he was an aethiest – but he was also a deep humanist and in fact won the prestigious G.D. Birla International Award for Humanism in 1990. Above all he was a very delightful and thought provoking conversationist.

Many of our fellow citizens have an image of science and of scientists we would find hard to recognize: They tend to think of science as something rigid, firm and soulless (and generally dull) created in an objective and often solitary manner by cool passionless persons. While they might be willing to see some nobility in 'pure' science, this reluctant generosity does usually not extend to its 'dirty' offshoot, technology. Absurd as all this picture looks to us, it is, I think, worth examining how these dangerous misconceptions arise and what might be done to improve the understanding of what we do.

These views are indeed dangerous in several respects. First there is the angry puzzlement that arises when no firm clear answer can be given to scientific queries that are of public interest (usually in the environmental or medical fields). When on some such issue different scientists hold differing views, journalists speak of "this extraordinary scientific controversy". When I tell them that controversy is normal in science and is indeed the lifeblood of scientific advance, they find it hard to believe me. The public tend to think that at least some of the scientists involved in such a controversy must be either venal or incompetent or both. These views arise partly from the conflict between the popular view that scientists are 'objective and dispassionate' and the normality of active arguments, yet people are unwilling to abandon their view. Moreover, the piece of science most people are familiar with is the Newtonian description of the solar system (Newton's clockwork, as I like to call it). The rigid predictability of this is taken as a model of what all science should be like. When this expectation is not fulfilled, there is disappointment.

A model, familiar to all, for many fields of science is weather forecasting, but this is not appreciated. The curse of rigidity is thought to apply to us and this view is reinforced by teaching mainly the examinable pieces of science where the right/wrong classification can readily be applied.

Secondly there is the denigration of technology arising from the widely held view that it is purely derivative and trails science. Thirdly and in some respects most importantly, there is the worry that it is on the basis of these widespread misconceptions that young people make their career choices of whether to become scientists or not. I feel sure that some who would have made excellent scientists were frightened off by the rigid image ("to every question there is just one right answer") so often conveyed at school, while some of those who become scientists guided by this image are disappointed to find their work full of uncertainties and question marks. We need the adventurous souls, but do little to attract them. I sometimes comment that if we were a business with a prospectus as misleading as the one of science so often presented at school, we would be in trouble with the law.

How have these misconceptions arisen and what can we do to avoid generating them? I think there are a number of reasons. Foremost perhaps is the understandable desire to get the maximum quantity of science taught in the necessarily limited amount of time available (at school or even in undergraduate courses) with no attention paid to the need to convey something of its spirit. Coupled with this is the wish to confine instruction to the supposedly certain parts of science to avoid teaching something that later turns out to be incorrect. In fact it would be most educational to convey wonder and uncertainty. Neither the philosophy of science nor its history are considered to be parts of the normal syllabus. Yet it would be very beneficial to go through some of the very intelligent ideas of our predecessors that turned out to be wrong.

I totally accept that teaching hours are limited. If time is given to describing the evolution of scientific ideas and how they were shaped by technological developments, then clearly the total amount of science covered will be less than it is now. In my view this would be a price well worth paying for educational as well as for scientific reasons and would demonstrate the intensely human nature of science.

Perhaps an example will help. Children are taught that the Earth goes round the Sun, but rarely about tests of this hypothesis and probably never about the historical development which in fact is fascinating and, as will be seen, could readily be taught.

By the late seventeenth century the Copernican system was accepted by virtually all astronomers. The great prize and test would be measure a stellar parallax, the apparent change in the position of a near star due the Earth changing its position during its orbit about the Sun. The inaccuracies of the instrumentation of the time, coupled with the difficulty of choosing a sufficiently near star, led to numerous unsubstantiated claims until the first unambiguous parallax was at last established by F.W. Bessel in 1838. But already in 1725 James Bradley had discovered stellar aberration, the apparent change in the position of stars due to the change in the Earth's velocity during its orbit. This was the first clear test of the heliocentric system and should surely be widely taught at school (the effect on the inferred direction of a star due to the motion of the telescope is readily described). This would be far more helpful than the mere assertion that the Earth orbits the Sun. The aberration angle is many times greater than the parallax angle of the nearest stars, which accounts for it having been discovered much earlier. It is amusing to speculate that, had our civilization developed on Jupiter, with its bigger orbit, but lower velocity, parallax would have been much larger and aberration rather less than here, so that presumably parallax would have been found first.

This story is a good example of scientific evolution, showing how it is driven by technological advances (the gradual improvement in the precision of astronomical measurements which eventually enabled Bessel to measure so small a parallax angle successfully), but also how a good scientist works: Bradley had originally not thought of the then unexpected phenomenon of stellar aberration, but very speedily worked it out to account for his otherwise inexplicable measurement of a stellar position shift at right angles to the parallax shift he was expecting to find.

In the philosophy of science I am a follower of Karl Popper. He sees the task of a scientist first to propose a theory that of course needs to be compatible with the empirical knowledge of the day, but that also must forecast what further, future experiments or observations will show. If such are performed and are incompatible with the theory, we say that it has been disproved. Liability to empirical disproof is the defining characteristic of science. If the tests turn out to be consonant with the forecasts of the theory, we must never regard this as a proof of it, since it remains scientific only if it continues to be liable to be disproved by further experiments. Thus all scientific insights should be viewed as provisional only. It is because the wholly unexpected can happen that science is such an adventure.

This analysis is appropriate because theories make general statements, whereas experiments and observations inevitably deal with the particular. This is also the reason why a theory can never be deduced from empirical knowledge. It necessarily requires a leap of the imagination to formulate one. Equally it is imagination that is needed to devise a novel experiment to test a theory. Thus imagination is essential in science, but do our fellow citizens appreciate this? It is natural that a scientist will argue fiercely to defend a favored theory, perhaps by criticizing the accuracy or reliability of an incompatible experiment, which will be defended by its originator with equal passion. If relating this were part of ordinary teaching, perhaps the absurd popular picture of the cold, unimaginative, passionless scientist would gradually fade away. But there is another point on which we ourselves may be somewhat vulnerable. Communication is essential in science. We fully accept this. This need makes me think of a customer coming into a pet shop asking to buy a parrot of especially high intelligence. After some consideration he is sold a particular bird. Two weeks later this customer returns to the shop absolutely furious because this reputedly so intelligent bird has not said a word in all this time. However the pet shop owner replies: This parrot is a thinker, not a talker. Indeed we do not regard any work as part of science until it has been widely communicated through being published in the accessible scientific literature. Yet do we consider the teaching of communication skills to have a legitimate claim on the time table of a science course? We all have the experience of a graduate student, highly competent in the relevant topic, yet finding it immensely difficult to convey the results in understandable form by the spoken or written word. Most of us eventually learn communication skills on the job, but do we give their early systematic acquisition the priority it deserves?

Nor do we often analyze the means of the conveying of information in depth. To me the printed word is of only modest effectiveness, though its permanence and wide distribution make it essential. The formal lecture is rather more efficient, but the less formal seminar or workshop are far better for exchanging information. Yet to chat to a few colleagues with a glass in one's hand is superior to all other methods, for then one is willing to talk about one's doubts and failures as much as about one's successes.

I want to return now to the relation between science and technology, which is so often misunderstood. It is implicit in Popper's definition of science that tomorrow we can test our theories more searchingly and thoroughly than we can today. This means that the progress of science depends on the advance of the methods of empirical testing, i.e. of the available technology. Of course equally technology can get ahead by using novel insights of science. Thus it is a mutual relation in which neither science nor technology can be called primary, with the other secondary. Perhaps I can illustrate my thinking with an example of this interaction.

Physics made enormous strides during the last quarter of the nineteenth century with the discovery of the electron, of ions, of radio-activity, etc. Why were such discoveries made then and not earlier or later? Most of such work requires the use of evacuated vessels. Their availability depends on the efficiency and reliability of the pumps needed to extract the air. It so happened that the machining of brass pistons and cylinders improved considerably in the 1850s and 1860s. Though this was an essential pre-condition, it was not sufficient. Any vacuum system inevitably develops leaks that have to be plugged. For non-moving parts, sealing wax is an old established efficient means, but it is rather rigid and thus cannot be used in the links between the vibrating pump and the experimental vessel. A reasonably suitable material became available at the time, namely plasticine. (One could therefore say that much of physics is ultimately based on plasticine). The availability of such a vacuum was a major technological step that allowed much scientific work to be done.

In due course the use of such reliably evacuated vessels permitted Roentgen to make his great scientific discovery of X-rays a hundred years ago. Their importance for medicine was soon appreciated (though it took much longer before their dangers were understood). Accordingly, a new technology of X-ray machines came into being that in due course made them affordable, reliable, precise and safe. Some fifty years after Roentgen, these machines were used to study the structure of organic materials and thus the new science of molecular biology came into being. This in turn gave birth, in time, to a wholly new technology, bio-technology. This is a clear example in which each advance of science or technology leads to an advance in the other. Neither can claim primacy.

The international nature of science is so strong and pervasive, because science is well tailored to our universal human characteristics, above all to our fallibility. Similarly it suits our sociability and our need to communicate. We value imagination and ingenuity highly, but the supreme yardstick of empirical test is recognized by all.

I would like to conclude with a personal story which illustrates some of these features. Many years ago my late colleague R.A. Lyttleton and I investigated the consequences that would arise if the electric charges of the electron and the proton were not exactly equal and opposite. (At the time this was only known to one part in 10^{13}). We showed that there would be very interesting astronomical and cosmological consequences if the discrepancy were as small as one part in 10^{19}. This paper irritated many. In their desire to prove us wrong, several very ingenious experiments were devised which showed that the maximum permissible discrepancy was less than one part in 10^{22}, far too small for the effects we had calculated. So within a very few years we had been disproved. However, I am proud of this paper and in no way ashamed. Thanks to the work which it provoked, an important constant of nature is known to much higher accuracy than before.

Following Popper, we know that empirical disproof is the seminal event to science. One can be right only for a limited time, but to be original and stimulating is the essential contribution a scientist can make to the unending adventure that is science.