5. Science speaks the truth and nothing but the truth but nowhere near the whole truth

Adapted from first version of CHE lecture, 20th November 2001. Ulrich Loening
Cartoons indicated thus. But not much used in this version of talk

Preliminary

I was awarded, long ago, the degree of D.Phil by the University of Oxford. Not PhD like the other place awards, but D.Phil, Doctor of Philosophy, in English, down to earth in a modern language.

My thesis had been titled "The Sulphur Chemistry of Proteins and related Compounds" - a lifetimes work commented my professor, Hans Krebs. But the actual substance of it was merely about the two sulphur links that hold together the two chains of the molecule of insulin, the hormone that controls your blood sugar and without which you suffer from diabetes. I entered into that very narrow reductionist remit in the hope and belief that detailed study of a little corner of nature, especially of the proteins which are the active constituents of all life, would give some insight and understanding of the greater whole. Perhaps it did, who can judge. What it also did is give me the license, but not necessarily the ability, to practice in the field of natural philosophy.

Philosophy. Science in the English speaking world is a catastrophically narrow word. For others, it covers every intellectual achievement, including those classed by us as arts subjects. For the purposes of this talk, I use the term 'science' in its wider meaning of natural philosophy. I want to try to use this license to distinguish ignorance, that of yet to be discovered things, from lack of the whole truth, due to misunderstanding. It might help us ponder how science can inform society about the great ecological dilemmas of today.

The physical beginnings

The origin of the scientific approach is remarkably recent. Through all the ages of human progress, the particular mentality that sought knowledge and understanding from observation, testing, generalisation and then testing again, gained strength only in the Renaissance; that is, by white Europeans around 1500 AD.

"Galileo's observation contains the whole essence of what gave Western man domination over the world; recording of regularities, compounding them into laws of nature, and designing experiments as the basic method of his new philosophy. The recipe is simple but has turned out to be eminently successful. The question has often been asked, why the great civilisations of the East did not develop science and technology. The answer to this question was once given by Einstein who pointed out that it is the wrong question. The miracle, he said, was not that the East failed to create experimental philosophy, but that the West did." "It would be rash to suggest that it was developed merely out of a desire to enslave others." (from Kurt Mendelsohnn) Yet it did and this was in fact the time of the start of the conquest of the world. Photo of ceiling in Wurzburg Residenz, centre of all peoples of the world. Perhaps the deep assumption of our civilisation, that the latest in science and its applications must be useful, had its origins in these early Galilean observations, which were done in the search for truth but led to conquest. Whatever the case, Galileo shook the accepted dogma of the times that stemmed from the classics. The search for truth became the aim and he said so explicitly. He took the first steps in separating reality from dogma.

Descarte admired Galileo in his times of trouble with the Pope, and expanded the new ideas. We now blame him for separating mind and matter and considering animals to work like machines. We see a new dualism thrust into the world, which has allowed us to conquer nature without feeling. But I prefer to see Descarte as taking a big step in separating fact or reality from myth, as Galileo had done from dogma. He tried to sort out that which could be analysed from that which would forever remain mythical and beyond grasp. We deny him at our peril; but of course we can now expand his narrow taxonomy of knowledge into a greater whole.

Newton could take the new rationality further. Merely the difference between an apple falling and the moon not, allowed him to generalise his findings into the principles we now call the laws of gravity and motion. These applied not just to apples but to the whole cosmos. Truth was expanded and a further mush of myths and beliefs was cleared up. The 3 body problem. Newton nevertheless continued to work in many of the more weird and mythical beliefs of the times, including alchemy and attempting conversion of lead to gold.

The essential feature of the foundation of this science, was its powers to predict beyond the situation; to generalise. If your washing machine fails and you take it to the shop to check, they do not question the laws of momentum or electricity, they look for faults in construction. So progress continued throughout the physical world. The limitations of the steam engine could be exactly predicted from the generalisations that became Carnot's Laws of thermodynamics. James Clerk Maxwell could predict that radio waves must exist before they were discovered, and here in Edinburgh in the building named after him, Peter Higgs could predict that there must exist another sub-atomic particle, now called the Higgs Boson.

Then Einstein could join Newton's two laws of gravity and momentum into the general theory of relativity. The latter, take note, did not deny Newton. Newton's Laws remained the whole truth, only the context had expanded.

The power that Europe obtained over nature and over other civilisations, rests on the success of this scientific method. There is no question, that from these early beginnings, truth and nothing but the truth was learned. No one would expect it to be the whole truth: Newton himself likened the scale of the further search to the vast numbers of pebbles on the seashore. Where the whole truth was missing, it was due to ignorance, not the principles of science. (I need here to stress the meaning of my use of prediction: it is not of the future, it is of the results of a physical action). Ignorance can be reduced and more findings integrated into generalisations. When Sir Cyril Hinshelwood, in my student days, anounced the second edition of his book on physical chemistry, he apologised that it was fatter than the first; had there been any progress in the subject, it should have been shorter.

But then of course, physics came upon two areas of uncertainty. At the atomic level, the observer necessarily becomes part of the observed: when the object becomes so small that the observation cannot but change it. And at the level of turbulence and chaos, where the flows of energy and material creates order along paths which cannot be predicted. Nevertheless science can state with certainty, that such uncertainties are not due to magic; there are no other forces that control the outcomes. The uncertainties are inherent in the physics. CHAOS

The laws of physics stand. In the current jargon, they are neither reductionist nor holistic but universal generalisations about all of matter. They rest on and confirm, a basic assumption that there is a unique interdependence of the constituents in the universe. The truth as we perceive it, is whole.

The expansion into biology

We proceed to biology, in which the uncertainties pose new problems and attempted generalisations like those in physics leave fuzzy edges. First, Pasteur, Mendel and Fleming and then Darwin.

By observing the asymmetry in crystals of tartaric acid, made either chemically or during fermentation in a wine bottle, Pasteur realised that only life could ferment grapes and make molecules of one handed symmetry without the other. The chemically made crystals included equal numbers of shapes that were mirror images of each other; the wine crystals had only one of these. The science of optical activity was born. Creative imagination let him generalise the common features of his findings, concluding that fermentation, and then also diseases, were caused only by living things, and that they could not generate from nothing. Here was an understanding about life that must represent the truth, and nothing but. Although ignorance remained greater than knowledge it was still possible to predict, for example that fermentation, disease and life, could not exist without life initially. When the Bucher brothers broke yeast cells open in about 1900, and found that the now lifeless brew could still continue fermentation, people denied Pasteur - he was wrong they claimed, because now fermentation could take place without life. Of course he was not, only the context had expanded, the principle stood, and biochemistry was born. With that there opened a whole new field, which as I will show later, did indeed manage to exclude some whole truth.

It was the same with Mendel; the contexts of his laws of genetics were narrow. Was he just lucky in choosing his examples? Probably not: he could see some regularities from long experience, he changed his attention from mice to peas, and must have chosen his experiments to demonstrate what he already perceived. We would not now accept his experiments for their design or their statistics. Yet they uncovered new truths and nothing but, yet nowhere near the whole. The whole that was missing was again largely due to ignorance of matters yet to be discovered, but also to understanding that may never be reachable, as we will see.

How much of such discoveries that led to generalisations in biology, were the results of chance findings? Pasteur said that chance only favoured the prepared mind.

Fleming's discovery of penicillin provides one of the best known examples. We all know how that chance fungus infected Fleming's petri dish of a growth of bacteria. Every child at school is taught that lesson, how clever Fleming was to spot its significance. It makes you think that chance matters, good luck was the origin of Fleming's discovery. But it wasn't. Fungi infect laboratory bacteria so frequently, that the chance was sure to happen – may indeed have already happened in Fleming's own lab dozens of times. There is nothing limiting about such chance – it is needed for the discovery but it is not its cause. The essential here was that Fleming's mind was prepared. He was actively looking for just such a phenomenon. He had already isolated the enzyme lysozyme, from tears and from egg white, which kill bacteria. As with Newton's apple and Pasteur's crystals, imaginative creativity yielded new interpretations and so new truths; principles which were generalisations reduced from many observations. But these were all simple; what happens when we look at biology in larger contexts? Future B.

The start of holistic biological sciences, from Darwin to ecology

Darwin was clearly correct in his analysis – species vary from each other and evolved into new forms of life. He thereby challenged the church and current belief and dogma, in much the way Galileo had done. But that does not necessarily mean that Darwin's hypothesis about the mechanism of evolution was adequate. The re-discovered genetics provided a richer understanding of inheritance and a very plausible explanation of how Darwin's idea could work. That became neo-Darwinism. This is the simple notion that random mutations create the variability from which natural selection ensures survival of the best. Here is a simple, brilliantly simple, generalisation that seems to compare to those early ones in physics. But here also we may see the beginning of a scientific denial of the whole truth. It might take a philosopher, not a scientist reared in the science of the physical world, to appreciate the question. Karl Popper was one such. Just imagine a pre-woodpecker finding that due to a mutation it has a stronger beak. Whoopee she says, now I can get insects out the bark of trees! Of course not. It has to be the bird that first tries, and then its most successful progeny will be those with stronger beaks. Mutations are not limiting. Quite the contrary, genetic inheritance is in constant drift and kept from drifting too far by the rigours of selection. It is not the genetic material that maintains the constancy of inheritance, any more than it is the environment that ensures the stability of the genes. The control is in the environment; the 'creativity' of evolution is in the organism in its environment. There is no shortage of chance. Random mutation and other genetic changes are so readily available, that they cannot be considered a "cause" of evolution, any more than the contaminating fungal infection was the cause of Fleming's discovery of penicillin. The two situations are formally similar in their logic.

The simplistic neo-Darwinian interpretation is given immense support from extreme situations. An agricultural one is the barley variety that was bred from strongly irradiated seed. This damages the genetic material, mortality is high, but from the survivors was obtained one of the commonest varieties grown here in the Lothians, for beer. Equally extreme was the resistance to DDT in mosquitoes, which they achieved by modifying features of their chromosomes and cell division. This shows how even universal cellular mechanisms are fluid, and can be forced to change if the pressure is high enough. Darwin's idea was right, but neo-Darwinism was only partially sufficient. The conclusion has to be that, if one forces the system, it might obey some simple mechanisms; in nature other forces are likely to operate as well.

If the role of mutation in evolution is much less than the simplistic interpretation of mutation and natural selection had suggested, then Truth is no longer whole. There is no straight-forward generalisation to be made, that adequately fits the facts.

The problem is, can one somehow understand better what is the driving force in evolution? What is the equivalent of Fleming's genius? Here it is not just the science that remains incomplete; it is not even clear how to ask the right question: what would one mean by the mechanism of evolution? Beyond Entropy.

Perhaps the Gaia Theory steps in here. This says that life develops such as to maintain conditions on Earth suitable for life. Lovelock was criticized on all sides, from biologists who said they knew all along that plants made the oxygen of the atmosphere, to everyone who maintained that life couldn't be conscious about what would be best for itself. But a simple model convinced all of their failure to have seen the point. The forces of maintaining homeostasis on the planet are the same as the forces of evolution – they are evolution: the creative forces of evolution must be the same as the creative forces that maintain the planet. Within this greater picture, the processes of mutation and selection must occur, together with a host of detailed mechanisms. These are now the subjects of Gaia research. Here is the application of the simple general laws of thermodynamics and chemical equilibrium, to give a broad insight into how life develops. A more nearly whole truth has emerged, which we failed to see before but which with hindsight we should have seen. It needed Lovelock's imagination, just as that petri dish need Fleming. The new insight allowed Satish Kumar to write: "the Gaia theory is one of the most imaginative scientific concepts of our time. There are environmentalists who see ecological solutions purely in rational and mechanistic terms and therefore in a less imaginative way." And then the Resurgence article on Gaia is entirely of rational mechanisms that explain Gaia!

I am one of those ecologists who see the Gaia idea in "rational and mechanistic terms." That is how it arose, that is what it is. Here is the golden opportunity for a synthesis between the two cultures, yet which has actually been taken to maintain the difference. Even more than that, those very greens who most enthusiastically embrace the Gaia idea, tend also to be those who most criticise the rational scientific. And *vice versa,* some most rational and creative scientists marginalise the holistic emergent characteristics of life that the Gaia idea stresses.

It is in this area, that scientific and cultural education must develop. That will come into my next talk. Ecological Education.

The information that makes life

The discovery of the structure of the genetic material opened biology further to reductionist analysis – to study of the parts, taken out of the whole. One could again do what Descarte did – separate the unknown mush from what could be grasped. And the success of this was so stupendous, it led to its own Central Dogma of Molecular Biology. It stated that genetic information, that which one would expect indeed did expect, to be the most subtle, complex, intractable of all the properties of life, was merely in the form of a linear code of chemical letters. This linear sequence of letters was transcribed from the genes of DNA to the intermediate carrier of the messenger, RNA and then decoded or translated into the linear letters of the protein amino acids. Here at last was a fundamental understanding of biology on a level with classical physics. It applies to the whole of life. Yet unlike the laws of physics, it cannot explain the whole of life. It explains the material and information flows; it does not touch the emergent properties of a living thing that makes it what it is. That emergence arises from the interacting complexities of the genes themselves with the complexities of the developing cells.

So the whole truth, whatever that may be, states that it cannot be reached. Somewhat like the unpredictable order arising out of chaos, in life a predictable order, the organism, arises out of the combination of genetic and cellular complexities.

In parentheses:
So deeply rooted in society did this become, that DNA was hailed as the blue-print for life, huge sums were spent on reading the whole of the genetic code for humans, every school and college repeatedly taught the simple facts. They were not and are not wrong in facts. But when for example, Howard Temin discovered a group of viruses which had no DNA, only the carrier RNA, and yet DNA was involved in their reproduction, his proposal remained sidelined by our biological colleagues. Only when he and Dave Baltimore shown that indeed the RNA was reverse transcribed into DNA in the cell, did Nature publish the headline: "Central Dogma Overthrown." Just because the information flowed in the unusual direction, in the same language of letters, did not overthrow anything but simplistic dogmatic assumptions. Scientists are also just as liable as anyone else, to sticking to unthinking dogma.

Richard Dawkins maintains his fundamentalist approach that the DNA of the genes mutates randomly and the rest of the organism exists as a product of natural selection that ensures that this set of genes survives. Hence his brilliant phrase, "the selfish gene". I think that that is being as satisfied with the simple "random mutation followed by selection" as one could be with the law of conservation of momentum. But whereas Newton's law generalised a simple finding in physics, evolution deals with the complex systems of biology and ecology. The same logic cannot necessarily apply; the same reduced generalisations cannot hold.

Einstein asked, "Nature is more complex than we understand; the question is whether nature is more complex than we can understand." Or are we waiting for the biological Einstein to illuminate a new general theory of development?

I must here add some words of warning. The absence of an explanation in scientific terms can lead two ways: one is to further research; the other is towards mystical beliefs. The two do not mix. Nothing is worse than to use an inadequate science to make what is a belief seem respectable. There may be much in a belief; a lot of science arose from beliefs. But half-way scientific explanations merely turn valuable beliefs into quackery. There may be much in acupuncture or homeopathy; but biology has not approached it deeply and pseudo-explanations are worse than useless. Rudolph Steiner's biodynamic agriculture works, look at any of their farms, but their science is so incomplete, better not apply it! There is no better way to avoid the whole truth, than to apply inadequate pieces out of context.

Further, while there is so much criticism of corporate take-over of science research and policy, it is the take-over by the public which may be the deeper cause for concern. The active omission of the whole and application of the parts alone (as I outline later), has led to public disillusionment. The wonders of "Tomorrows World" on TV, of the exaggeration of the Human Genome project to justify its funding, and of the promises of safety in the face of trouble, all involve neglecting parts of the more whole truths. Patience for the whole has worn thin, and true scientific freedom is threatened.

Bring all that philosophy down to earth - apply science to what we see and what we can do.

There are much more immediate, obvious and practical rather than philosophical ways in which the science of biology fails to speak the whole truth. I will now discuss these, as applied to agriculture.

All the above, Pasteur, Darwin, Mendel, Fleming, were observers. Those below could make their arguments only by being economical with the truth.

1. Liebig is considered the father of modern chemical agriculture. Liebig showed that plants *could* take up nitrogen, potash and phosphorus as soluble salts and, with carbon from the air, obtain all their needs that way. But that does not mean that plants *do* obtain their nutrients like that. You can grow plants in water, but usually they grow in soil. Observations of a more sophisticated kind (microscopes, measurements of soil-bound and -free nutrients etc) might have shown, and later did show, that most nutrients are in fact taken up with the help of micro-organisms, mycorrhiza associated with the roots, and so on. Thus modern agriculture was born on an unnecessarily incomplete understanding of what actually happens nature. Soil and culture. The agrochemical industry was started on a piece of science that omitted aspects of biology that were immediately relevant to the matter. At the time, perhaps this was not known, the lack of the whole truth was due to ignorance. But it was not long before microscopists and fungal biologists found out. This did not change a successful agricultural practice. (To be fair to Liebig, he did see the point and changed his views later; but society took no notice).
2. Among the practices that followed the use of soluble fertilisers, were pesticides and later herbicides. These are extensively researched chemicals,

tested for safety, effectiveness and reliability. They work. But beside the extensive knowledge gained was also an area of deep ignorance: these materials are poisons and they do affect the crop plant; its physiology and biochemistry is temporarily disturbed and the plants become more, not less, susceptible to pests and disease. Amazingly, a Royal Society conference on biological methods of pest control, to avoid the disadvantages of poisons, failed even to consider the physiological health of the plant. Thus a whole area of potential agricultural pest management has been neglected, through being economical with the wider truths. Chaboussou.

3. Of course, the prime case of application of a partial biology is the insertion of foreign genes in crop plants. Here the exact knowledge of a gene and its ability to code for a particular protein is used to make the host crop plant systhesise that protein. The interactive functions of the genome cannot come into consideration. Most of the relevant understanding is omitted from the application. The science has been narrowed even below the levels of the known.
4. Perhaps the most ridiculous of scientific arguments is that for "substantial equivalence" of genetically engineered crops, to their conventional counter-parts. Here the whole idea is to avoid the whole truth. With the whole truth, the concept would collapse. At almost every stage of its life cycle, the engineered crop is not "substantially equivalent" by design. The whole point of having it is to act out its new function, be it a pest poison or herbicide resistance. Perhaps at the wholesale stage it can be regarded as equivalent; but then when it reaches the table, the diner may wish to know how her meal was grown.
5. A similar argument which can stand only by avoiding the whole truth, is a question of poisons in nature. In the arguments over the safety of organic produce compared to conventionally farmed, the pro-GM biotechnologists have repeatedly cited a number of papers in PNAS by Bruce Ames and colleagues. These show how there are thousands of times more poisons in nature than introduced by the agro-chemical industry, and that we eat thousands of times more of these than of the traces of pesticides remaining in our food. Hence, they argue, organic agriculture is much less safe than conventional. Wizard. At least one of my former students, now head of a vegetable research station, refuses to let his family buy organic produce. What is missing here, is any considerations of the role of poisons in nature. They are part of the ecosystem - without a range of substances of all sorts, by which plants and other organisms communicate, attract and repel each other, there could be no life of much diversity on Earth. And in general these materials exist only in their homes - belladonna does not spread into the fat or blood of polar bears as DDT does. Of course there are some poisons to be avoided. And we can now avoid the worst of nature's poisons that might

affect us: like the aflotoxins from fungal infections. So the biotech's argument has no basis in fact.

6. We can take this further, into "alternative" or "natural" cures and medicine. Most pharmaceuticals are based on natural origins. What is the justification for the herbal medicine instead of the conventional pharmaceutical? It is, that the commercial is highly purified, that natural includes a range of similar substances and many others beside. The idea that a cure is one compound necessarily omits what may be much of the whole truth, of the synergic actions of the complex.
7. Similarly, the health giving values of fresh fruit and vegetables remain not understood. We can appreciate vitamins, fibre and various other desirable substances. But there is a consensus that these do not add up to the valuable effects of green stuffs. There are ideas, there is little knowledge. But we know we are ignorant.
8. However, there are good reliable reports of the health values of crops grown on soils with their full complement of mycorrhiza and other, mostly unknown micro-organisms. Albert Howard described how in the early 20th century, his cows could rub noses with FMD infected cattle next door, without getting infected, over some 15 years. Biology teaches us, as it taught Pasteur, that observation, not necessarily intervention, is the valuable tool. If you cannot make generalisations like the physicists did, then that leaves a large pool of truth that is missing. So be it. Howard's work has not been followed up.
9. Perhaps the most damaging of narrowed agricultural science was highlighted by the BSE crisis. The overall picture was much clearer than the details, so painstakingly gathered together in the Philips Report. That report finally could not reach a conclusion about the ultimate causes of BSE, other than GOK! There may yet lurk here a biological revolution that challenges accepted dogma: that the diseased prion protein is created by chemical influences and can pass on its abnormal structure to the normal. That amounts to inheritance of acquired characterisitcs, and without any genetic material.

Conclusions

I distinguished two ways of making scientific progress in biology - the observational and the interventionist. The first does not affect the system, the second necessarily does.

In ordinary physics and chemistry such a distinction is not relevant. Both are necessarily observational, however complex an experiment. A chemical reaction is just that and no more; it does not change because we are watching it, nor even because we made it happen in a test-tube. A physical phenomenon similarly is not invalidated under enforced conditions (Galileo used inclined slopes to be able to measure acceleration due to gravity); until of course one reaches those quantum levels. But in biology and ecology there is a choice. The biological examples I chose for the first part of this talk – Pasteur, Mendel and Fleming - all observed; they did not intervene in the processes under study, although they all did experiments. But in many other sorts of biological investigations, it is the power of analysis created by isolating the matter of interest that also necessarily intervenes in the process and may fundamentally change it. Most of biochemistry is like that. Under these situations, given that it is the whole and not merely the parts that lives, much of relevance will be omitted.

It strikes me that almost the whole of agricultural science, as researched and taught in universities and as applied in farming, is of the interventionist sort. It adapted the system to suit what was wanted and tested to see if it works. That does not mean that it is how it works in nature, only that within the confines of the trial, that it can work. It almost inevitably fails to speak the whole truth, even of that which is known. And the results of such interventionist research may not yield the best systems. It augers poorly for the future of agricultural research in the UK, that the ARC changed its name to BBSRC, with the remit to create wealth for the country. This could not be better designed to externalise much of what should be its subject matter.

Organic agriculture is the attempt to overcome some of such problems of incomplete science: the base on which it operates is what already exists in nature; the whole is necessarily there. Improvements come from observation; and the only intervention is gradual through the experience slowly gained. This amounts to the application of Soft Biotechnologies. In such a way, one sees progress, soundly based on science and experience, for a new re-generative agriculture. Easter.