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Scientists as Citizens

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Abstract

The text is printed of a public lecture on the position of scientists in society, and the dilemmas facing scientists as a small minority possessing new information and perspectives which the majority does not yet accept or understand.

Since the Royal Australian Chemical Institute celebrates its 75th anniversary this year, and so do I, it seems appropriate to speak of the changes that these years have seen, and how they affect the present and future role of scientists as part of the communities in which they live and work.

It has been my good luck to spend all my working life in the borderland between physical and biological sciences, and to retain an active interest in them both. But I must begin by limiting my right, or the right of any scientist, to speak for science as a whole. It may once have been possible for one human brain to grasp the essentials of all sciences, but not now, not ever again. Even in my own discipline, organic chemistry, I keep having to make assumptions that I have not tested. I accept, without full belief, the findings of fellow scientists in fields where I have no expertise. They do the same with my findings. Something must tie me to these scientists, and them to me. What is it?

The art of the probable

It is certainly not faith; it is more tentative and incomplete. What one scientist assumes in a statement by another is that evidence about it has been recorded and can be checked, and that facts incompatible with it have been looked for and not found. It is never acceptable as a final statement of truth; it can serve, until upset or absorbed by something better, as a basis for further work that will approach the truth more closely. Science is the art of the probable; and I am using that word not just in its modern sense of "likely", but in its older and more exact meaning: "testable".

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Scientists do not believe; they check. And I am not asking you to believe anything I say on a scientific matter; only that there is tested evidence for all of it, and that I know the nature of that evidence and can make a judgment of its worth.

It may seem odd that a system of knowledge based on doubt could have been the driving force in constructing modern civilization. At its foundation in 1660 the Royal Society of London, for improving natural knowledge, was given by a quaint and still surviving custom a coat of arms and a motto. One motto considered was "Quantum nescimus", which translates as "What a lot we don't know". It is a good motto and I don't know why it was not adopted. Perhaps some much mistaken person thought that it wouldn't be true for long enough. In the end, the one chosen was "Nullius in verba". This means, from its original context, "We take nobody's word for it".

Anyone, of course, can disbelieve anything, but a scientist's unbelief also carries an obligation. You may make interpretations of what has been found out, but you must not believe them to be wholly true or complete; you or your successors must look again, and look beyond. Again, many people find perpetual unbelief a most uncomfortable idea, especially as a basis for action. But once you have accepted, as a scientist, that there are probabilities but no certainties, there is nothing unnatural in acting on your judgment of the odds for and against. That is what we all do most of the time, even if we do not always know it. And when I say "we" in this lecture, I don't mean scientists, I mean the whole human species.

Where and what we are

Here now are some statements about the position of that species in space and time. The evidence for them has been gathered by scientists of many disciplines. In their judgment, and mine, some of the numbers will be modified a little by future observations but the scale is correct.

Our sun is one of about a hundred billion stars—about the same number as the cells in a human brain—assembled in a spiral galaxy, one of innumerable galaxies populating the observable universe. Our galaxy is not an unusually large one, but light takes about one hundred thousand years to cross it. This compares with the four years light takes to reach our sun from its nearest neighbours among the stars, and the eight minutes that the sun's light takes to reach the earth.

Our sun is possibly rather unusual in being surrounded by planets. It was formed nearly five billion years ago. It stays hot by a process that we are trying to imitate on earth: the fusion of hydrogen atoms. In five billion years or so from now, the sun's hydrogen will be spent and the sun will become a red giant star, then a white dwarf, then a black dwarf. The earth as the third planet outward from the sun will be greatly affected by these changes.

This earth condensed from gas and dust around four and a half billion years ago. For much of that time there has been life on earth, and life has greatly modified the earth's climate. The species of life that we call human has been around for less than $0{\cdot}1\%$ of that time. It has recently examined the other planets in the solar system and has concluded that life is unlikely to exist or to be easily sustainable on any of them.

Nearly all of that information has been acquired in the Institute's lifetime, and mine. For the first time ever, the human species has been able to place itself in space and time. We know how short a time we have been here as a species; we know, barring a cosmic accident that we cannot yet predict or prevent, that we might inhabit the earth for billions of years to come; and we know no other place that we could colonize in large numbers. If we are citizens of anything, we are citizens of the earth.

And at an increasing pace we are finding out *what* we are. I am one of those who were privileged to take part in the revolutionary development of biological and biochemical science. When the Institute was founded, the structures of the vitamins and hormones, the proteins and nucleic acids, the complex sugars and lipids, the enzymes and coenzymes, the blood and leaf pigments, the transmitters of nervous impulses.... were all unknown. Today all are known, and, by the time this Institute celebrates its centenary, it may well be possible to write full chemical descriptions of many living things.

The studies of function have kept pace with the structural information. And with this knowledge has come the surprise that we, and all living things, cannot be regarded as individual collections of matter with a certain life-span: for the whole of our lives we are incessantly being torn down and built up anew, dying and being reborn at every moment. And in the most revolutionary development of all, the organizers, conductors and controllers of this molecular dance are being identified. The code of instructions stored in the nucleic acids has been cracked; the instructions themselves can be read out. The processes and agents by which harmony is imposed on a dauntingly complex network of simultaneous chemical changes are becoming clearer. The complete functional description of a living organism is a more distant goal than a description of its chemical composition, but that goal too is in sight.

It is a lovely paradox that this flood of new information, this revelation of complexity, has served to emphasize the essential unity of life; and the closer one gets to the chemical and biochemical essentials, the greater is the unity. The family tree of life is being redrawn and extended in the light of much more accurate and intimate knowledge of the differences between species. The evidence gets stronger all the time: the human species is a very recent development in a single process that has been evolving on earth for around three billion years. And once again, the time scale and the detailed knowledge are almost wholly products of my lifetime.

Scientists and what they do

The people who acquired all this information and much more, and who are testing it and adding to it all the time, have never amounted to 1% of the population of any country. Worldwide, the proportion is more like one in a thousand. They share an intense, usually lifelong, curiosity about everything around them, and with the curiosity they have, or they acquire, sufficient discipline to question their own findings, not just the findings of others. They are impelled to make patterns of what they learn, even while they know that the patterns are imperfect. I have to call them scientists because that is the accepted term for them and they are stuck with it; but the Latin root of the word suggests a system of knowledge, not the real system of increasing probability and residual doubt.

Not many scientists can spend a whole working lifetime satisfying their curiosity. There never have been many ivory towers; and for the past 150 years most of the discoveries have been made by people who earned their living as teachers. Nowadays, the sheer usefulness of science and the multitude of its applications to civilized life have led to the present situation that most scientists spend their careers in applying the results of earlier work, not in extending the frontier. From my own standpoint as a chemist, one gets a particularly broad view of the ways in which science interpenetrates the fabric of modern society, because the business of chemists is matter: the stuff that everything and everyone are made of. Chemists have arrived at a fairly satisfactory understanding of what matter is, and how it behaves. Give them a sample of matter and they can tell you of what elements it is composed, how much of each element there is, and how these elements are combined. With increasing facility they also compose new forms of matter from old, and they are becoming cleverer all the time at predicting the properties of compositions before they make them. That seems rather a bald statement of what they do, until you consider its scope. Look first at their power of detecting and identifying and measuring what is there. Many samples of matter can now be analysed without visibly changing them. The 400+ components of the smell of coffee are a different proposition, but they too have been separated and identified. This analytical power means that chemists are employed to monitor the purity and safety of practically every product that civilized people use: the food we eat, the water we drink, the air we breathe, the seas that surround us and the earth we tread .... and not only that, chemical examinations of existing processes and products are continually showing many industries what they must do to maintain and improve quality, and to cut down waste and pollution. And the "natural products" chemists who look at and identify the chemical components of plants have initiated several large industries.

The chemists who create new compositions of matter have transformed, to an even greater extent, the modern world. They began to do this not much more than a century ago, starting with things like dyestuffs and medicines that are valuable but not needed in very large quantity. Sometimes, the things that they learned to produce were already known in nature; now, most products have no natural equivalent, they were created to satisfy the wants of an ever more complex society. New metals, plastics, composites, textiles, adhesives, coatings, rubbers, insulators, conductors, semiconductors, superconductors, optical fibres, detergents, ceramics .... the list is much longer than this, and chemists created the material for them all.

A physicist, a mathematician, a biologist or an earth scientist could tell similar stories. Scientists are embedded in the fabric of modern society and most of them spend their whole careers responding to the demands of the state or the market. They are so useful that the overwhelming majority who are non-scientists assume that that is what they are there for. To an increasing extent this majority is insisting that scientists ought to concentrate more on what society says it wants from them; and as for the teachers of science in schools and universities, their business is to train people who will continue to satisfy these wants. Scientists generally do an admirable job in responding to these demands, but their knowledge is imperfect and the exploitation of their discoveries is usually taken out of their hands. Sometimes, not often, a product or a process does unintended harm to people or to the biosphere; and then the blame is often on the discoverers, not those who recklessly exploited the findings or spread the harm. I do not say that scientists are always free from guilt: I shall be talking of their weaknesses later on. But when scientists are condemned by people who are too lazy to learn anything about science but who have no intention of giving up the comfort, health and enhanced quality of life that science has brought them, I recall Caliban's curse from *The Tempest*.

> Thou taught'st me language, and my profit on't
> Is, I know how to curse: the red plague rid you
> For learning me your language!

If one accepts the majority view that scientists are useful servants who must do as they are told, "always on tap, never on top", there is no problem. Scientists may legitimately strive for better pay, higher status, more facilities; and they may form Institutes like the RACI to further these aims and to exclude unsuitably qualified people. But during the lifetime of that Institute, new and increasingly extensive and precise information has changed the world outlook of all scientists. And if you are the servant of a master whom you know to be selling the family silver, mortgaging the land, and spending the capital on amusing himself, fighting his neighbours, and producing too many children with similar inclinations, you will probably look for another place before the crash comes.

But there *is* no other place, and scientists cannot opt out of society. So it may be useful to look at the dilemmas confronting a member of society who is also a committed scientist.

The dilemmas of secrecy

The dilemma of nationality is obvious. Science is and always has been international. I still like experimental chemistry and my bench at Sussex University is in a large room where chemists of nine nationalities are working now, and where nine other nationalities have worked recently. We like to compare cultures but it is our discipline that ties us together. Yet all of us were born in nation-states that imposed duties and constraints on us from birth. The wall of my classroom in a primary school at Armidale in New South Wales had a large poster of a flag with the legend "It's our flag. Fight for it. Work for it." This was 1923 or 1924 and even at the age of six I thought it odd that the flag was the Union Jack. Still, the imperatives are the same whatever the flag. In democracies you are allowed, after you grow up, to exercise every few years a choice between representatives whom, as individuals, you normally did not select. In return for this right you are subject to all the requirements that a national government may impose. If you become a scientist, you are often asked to contribute your knowledge and ingenuity to preparations for international war. You are then in hostile competition with scientists of other nations whether you like it or not, and this means keeping scientific findings secret, however valuable they may be to humanity.

The demands of industry present other dilemmas. Multinational companies are our real masters now. Such companies employ scientists to create, improve and monitor their products and processes. Often, original research is required and new findings of general interest may be made. The scientists who do this work are left in no doubt that they are competing with scientists of rival companies and that their findings are secret. Publication, except for patents, is permitted only when the work is of no perceived value to competitors. I can think of several cases—and there must be many, many more—where work remained hidden until it was rediscovered and published by someone else, and of valuable work that remains unpublished to this day. However necessary it is in the short term for companies to make profits, the longer-term cost is to the scientists and to science. The pressure of industry to generate short-term profit is always tending to reduce industrial scientists to the level of parasites on the body of scientific knowledge.

Similar pressures are developing on scientists in universities and in government research institutions. Everywhere, governments are telling scientists that their research should become more "relevant" to perceived national requirements and to industries. Well, it does happen sometimes that an important discovery is made at an institute set up for the purpose of making it; but this is infrequent, let alone typical. Here is an actual and far more typical case. Some people decided to examine the effect of an electric field on living cells. They generated this field between two platinum surfaces immersed in the liquid culture medium. The cells died. But the people who did the experiment were real scientists who resisted the obvious conclusion and found that the cells were not being killed by the electric field, but poisoned by tiny traces of dissolved platinum. They mentioned their finding to a colleague, who looked for and found a stronger effect on cancer cells. A search in the chemical literature for soluble compounds of platinum turned up a substance that had been made nearly one hundred years ago by a chemist in another country whose interest was simply to explore platinum chemistry. This compound was even more effective against the cancer cells. In the event, a large number of people are alive today who would be dead but for this constructive but unfocused curiosity of several scientists separated by discipline, nation, and time. The factors combined in this success were curiosity, scepticism, good communication, and publication of results. Together, these produced an outcome that nobody predicted or expected; and that is the essence of research. But it has always been difficult to persuade those who finance research that predictable results are worthless and that the best hope is to employ the team that makes the vital connections between other people's results and, sometimes, their own.

The dilemmas of history

So scientists have these dilemmas, that their role as loyal citizens and employees, and respectable members of society, can be in conflict with their science, based as it is on free exchange and recording of information. Another dilemma facing scientists arises from what you might call their sense of history. As I pointed out earlier, scientists have excellent evidence that the mental powers distinguishing the human species have developed to their present level in a tiny fraction of the time that life has been on earth, and an even smaller fraction of its potential future. The nature of the life we know on earth is to dissipate energy while using part of it to maintain for a short time a particular pattern, and to replicate this pattern with small variations before the original is lost. Very sensibly, practically all present forms of life depend directly or indirectly on sunlight, the most constant energy source of all. The development of complexity that resulted, quite recently, in the evolution of human intellect can be seen as one possible response to the challenge of passing on the pattern of a species before all its individuals die. Death of the individual is unmistakably the driving force.

Scientists have no way of measuring whether any pressure exists *now* on the human species to improve its intellect. But as they discover more about the earth and about our unity with other life, they can see all too clearly some of the origins and consequences of our present behaviour. For most of its existence the human species has occupied its biological niche as a parasite on the ability of green plants to collect solar energy, and as a predator of other animals that do the same. A few hundred years ago—a mere breath of time—a concentrated source of energy was discovered in the fossil fuels: essentially, the energy of old sunlight trapped by life and buried by the earth. Humanity has exploited this resource with all the restraint of a fox in a chicken house.

The normal response of a species that suddenly discovers an abundant irreplaceable source of food is expansion of population to the limit, followed by mass starvation when the supply runs out. To the extent that we are using fossil fuel as food: making fertilizers to increase crop yields, manufacturing and fuelling machinery to cultivate and irrigate and harvest and transport food, we are following the same pattern. But most of the fossil fuel is spent on uses that are totally frivolous when measured against the basic needs for survival. And as a chemist I just hate to see all that lovely irreplaceable raw material going up in smoke. In one way, an oil refinery epitomizes the waste of this precious essence of old sunshine, since most of its product will be burned in engines and under boilers. In another way, though, it resembles the economy of living things: from its many streams, hundreds of useful products will be made, and burning is like excretion: the last resort, when no other use can be found. Perhaps that is one of the few good auguries for the time when our successors will have to manage without fossil fuel.

But the dilemma is this: the historical perspective that I have outlined is peculiar to scientists. But scientists are a small minority, and people conversant with science, let alone scientists, are a small minority in administration, government and (in most countries, including this one) business. The perspective of the politician does not usually extend beyond the next election. The unborn have no vote, whereas the easiest way to get the votes of the majority is to promise them increases in their power to consume. The average citizen's reaction is: "What did posterity ever do for me?" The administrator seldom has a scientific background, or any remit to consider an extended future. The businessman wants to make profits—the quicker the better—for himself or his shareholders. Among all these people there seems to be a general vague expectation, if they think of the matter at all, that the scientists are sure to find some way to rescue future generations from the shit into which the present one is dropping them. And sometimes they would add that the mess is of the scientists' creation, not theirs. So, if you are a scientist and you have this perspective, you realize before long that if the future is in anyone's hands it is in yours; and you can recognize some of your actions, although they might be innocent or even praiseworthy from a civic point of view, as hostile to the future of your species, or at least to a large number of its future members.

How you react to this dilemma depends on what I will call, though in a special sense, your politics. If you judge that overpopulation, poverty and mass starvation are inevitable for the great majority of the species, you may concentrate on the survival of a wealthy minority that can monopolize the world's limited resources. On this view, the future as well as the present depend on competition for survival within the dominant species. That view is widespread, especially in the United States; and a recent British prime minister claimed that there is no such thing as society, only competing individuals and families. The dilemma then vanishes: you best serve the future of your species by depriving and if necessary fighting your weaker neighbours, and if, for instance, you are a scientist employed by a tobacco company, you may see nothing wrong in selling and pushing a lethal addictive drug to the underclass in your own country or to suitably ignorant and gullible people abroad.

If, on the other hand, you judge that widespread human disaster is not inevitable; that the main internal enemies of the human species are ignorance, bigotry and oppression; that the advances of science in understanding and improving the human condition have been made more by co-operation than by competition; and that the chance of further evolution in our species may no longer depend (as it certainly did in the past) on a continued struggle for survival, the horns of your dilemma are sharper. To give the human species its best chance to find out more about what it is, what it can do, and where it can go, you need a sustainable earth that does not exhaust its resources—animal, vegetable, or mineral! That is much more difficult, in the short term anyway.

The dilemma of truth

The last dilemma I call the dilemma of truth. In England, I live on a hill opposite the old and historic town of Lewes. There is an obelisk on that hillside; I pass it nearly every day. It bears an inscription beginning:

In loving memory
Of the undernamed seventeen Protestant martyrs
Who for their faithful testimony to
GOD'S TRUTH
Were during the reign of Queen Mary
BURNED TO DEATH
In front of the Star Inn, now the Town Hall, Lewes...

There are several deep ironies engraved on that stone. First, the people who burned these unfortunates were equally obstinate in their belief that they were defending God's truth against dangerous heresy. Secondly, this monument was erected, 350 years after the event, with the purpose of keeping sectarian division alive; and even now, nearly a century further on, people of the same two sects are killing each other in Northern Ireland. But perhaps the supreme irony is that although there are several hundred religions now, and there have been many more, each of them claims to be true and exacts belief from its members and, most unfortunately, their children. Certainly, there is a widespread fear of personal death, and if you offer eternal life in exchange for eternal credulity—as most religions do—you will find many takers. But the side effect, that belief beyond reason is regarded as virtuous, has been very damaging to the human species: and, as ever, most of the harm is done by the people who are most convinced that they are right.

The discipline of science generates a special relationship with truth. There is what I will call public truth: the obligation to record what you have done as accurately as you can, never fabricating, never distorting, and never suppressing findings unfavourable to your conclusions. Private truth is even more important. As a scientist interacting with your experiments, you receive an education in the implacability of truth and in your own capacity to be deceived by your expectations, your hopes, or just your stupidity, that is unlike any other experience I know. And you may find the worst deceit in what religious people might call inspiration or revelation. We all know the euphoria that comes from suddenly seeing something in a new light, and the more elements that seem to take part in the new pattern, the stronger the feeling. But as every scientist finds out, the feeling is not less strong for mistaken visions than for those that will survive a cold examination. You must lean over backwards, as Feynman put it, to resist belief. All this is very different from the attitude in other professions. For a politician, truth is something to hide and twist, and to tell only when it is entirely favourable. For the media, truth is of secondary importance except sometimes as a defence to an action for libel or slander. For advertising people, truth is like the pinch of baking powder in a muffin—it puffs up a mass of misdirection into something that the public will swallow. For lawyers, decisions have to be reached on incomplete and at times artificially restricted data. The legal profession insists on making witnesses swear an impossible oath about the truth, but its members do not take that oath, and its judges are less interested in the discovery of truth than in the observation of legal form.

The faults of science

I don't wish to leave you with the impression that I think of scientists as latter-day saints, so I had better get on to their weaknesses: not the human weaknesses, though scientists have their full share of those, but the failings that stem from their own practices and even from their own success. One of the chronic weaknesses arises from their own experimental method. When scientists study a problem experimentally they invariably begin by simplifying it, trying to remove disturbing influences that make observations, especially measurements, more difficult. It is a powerful technique and our present information about the physical and biological world has been built up by applying it. The trouble begins when you start integrating the results into more complex situations—and practically every situation to do with life is extremely complex.

A good example, one of many, is provided by the insecticide DDT. Its high insect-killing power and low human toxicity were discovered around 50 years ago. It is easy and cheap to make in bulk. Its first major success was to stop a typhus epidemic in its tracks—something that had never been done before. Its use against malaria-carrying mosquitoes has probably saved several million human lives.

But it was indiscriminate and persistent, and it worked its way up food chains until it did definite harm to some predators and was detectable in the fat of practically every human being. Detectable, mind you, only by methods that scientists developed for the purpose: the actual quantities were tiny. It taught chemists a lesson that they learned well—not to let biologically persistent molecules loose in large quantity. But if there is a wider lesson to be learned, perhaps it is that all new discoveries have to be introduced gradually and with circumspection. If that lesson had been heeded, the parallel fiasco of power from nuclear fission might have been avoided, and our species might now be enjoying a safe, judicious and unfeared expansion of this useful source of energy. I think we should all hope that, when fusion power comes, we shall act more wisely. As it is, people have the feeling that scientists are not wise enough always to know when they are doing harm; and people are right.

The tendency to oversimplify is linked with another weakness: scientists are apt to overvalue the importance of new discoveries, and to underrate the extent of their own ignorance. Many pressures reinforce this tendency. The status of scientists is strongly influenced by public as well as peer assessment of their work's importance; and when scientists are debating matters of public interest they are sometimes led into arrogance by the fact that their evidence does, usually, stand up to closer scrutiny than that of their adversaries. In short: as citizens they cannot afford to be humble, but as scientists they must be. Society makes it hard for them to see that the public trust that they need as a profession must come from refusal as individuals to go beyond the fact.

The third weakness is of more recent growth and it stems from the success of science. The information that sustained earlier civilizations could be handed down from parent to child, from master to apprentice; and while each craft was within the compass of one brain, the only thing that could break the chain was extinction of the culture, as sometimes did happen. Now, we have an enormous and growing mass of information, much of it tested. This information is immensely valuable: it comprises in fact our inheritable wealth, and there is far too much of it to be stored in human brains, even if brains were reliable storehouses. It exists as records of what has been done, and it is the basis for further advance. One might have expected that scientists would have understood the absolute need for fast access to *all* this information by *all* scientists. The techniques to do this, based on discoveries made and technologies developed during the past half century, are already available. Unfortunately, a concerted effort is required and that effort has not been made. As a result, scientists of different disciplines are understanding each other less and less, the search for information outside their own speciality becomes more and more laborious, and cross-fertilization of ideas becomes rarer. It will be hard to persuade society to give scientists the additional resources needed to get existing information properly organized and instantly available; it would be even more painful to allocate a greater share of present resources for that purpose, at the expense of research. But lasting benefits to science and to society would follow as day follows night.

The strength of science

I have tried in this lecture to show the main interactions and conflicts between scientists and the communities which have produced them. Many things are wrong with this relationship, most of them because scientists are a small minority whom the majority cannot understand. In our adversarial society, they must put their case in a court where there is no judge, no jury, and no rules of evidence; and where their regard for the truth is often a hindrance. Because they have an enormous amount of useful but difficult knowledge that does work very well indeed, their constant temptation is to become a priesthood, wrapped in mystery and competing for belief. Their true strength is to seek something quite different. I cannot put it better than Shaw did in his nearly forgotten play, *Back to Methuselah*:

> But my ways did not work; and theirs did; and they were able to tell me why. That is their only power over me; they seek no other power.

Scientists need to try harder to show that true strength, which essentially is that they thrive on being doubted. In this, they differ from all others among the shapers of society. I should like to see a different emphasis put on the teaching of science, an emphasis that would reflect the truth that the sciences *are* different from nearly all other subjects taught. Languages, literature, religion, law, art, music, even pure mathematics are all human constructions, and they can be taught on the basis that "these things are so because men made them so". But the sciences deal with the natural world, which men did not make at all; and the honest way to teach them is "these things are probably so because of this, and this, and this". The student will become a scientist all the faster by doubting the teacher and looking at the evidence: no lesson is learned so well as the one you teach yourself. And for students who will not become scientists, the habit of asking questions like "Who says so? How do they know? What's missing? What are the assumptions? What is the scale? Is it all about the same thing? Do the figures make sense?" will make them more receptive to the message of science for the rest of their lives. To be sure, the propagation of that attitude will cause a lot of grief among politicians, priests, mediamen, advertisers, barristers, diplomats, and other salesmen of all kinds, who can be relied on to oppose these educational reforms. But in the end, scientists have some influence on how science is taught; and they have in the schools the opportunity to start the sceptical revolution. Our species does desperately need to review critically its position and prospects, and to understand that this review has only become possible in spite of, not because of, our habits of opposing, oppressing and killing each other.