# Science and Citizens

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Delivered by
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ST GEORGE'S HOUSE nurturing wisdom

Imagine, if you will, an immense spherical chamber almost as tall as this wonderful chapel. It is approximately 5 m from top to bottom in height and it is surrounded by a layer of concrete over two foot thick. 192 of the most powerful lasers in the world are channelled through portholes in this massive empty sphere. Each laser is over 300 m long and the whole installation is shielded, being surrounded by another wall of concrete approximately five feet thick. The building in which these lasers are housed is about the size of two Wembley Stadia but this massive edifice is not in North London, but in North California about an hour's drive from the centre of San Francisco in a rather uninspiring small town called Livermore.

Projecting into the chamber is a long robotically controlled probe, which can be moved around this space by remote control, and viewed on a computer screen. At the very end of the probe, right in the centre of the chamber, is a tiny gold capsule about the size of the tip of my finger. Inside this delicate little capsule there is a minuscule pellet of frozen deuterium about 2mm across – and, using amazingly accurate engineering - each of the 192 lasers is precisely focused directly on this tiny pellet. When an alarm sounds and all the massive concrete doors are swung shut, the lasers can be switched on for a very brief moment. When they are in operation, they consume more power than that produced by entire National Grid of the United States of America.

In that moment – when the lasers are turned on, the enormous power focused on this tiny pellet compresses it; and that pressure, together with the immense heat generated, fuses the protons in the atoms of deuterium. This is an attempt at nuclear fusion, potentially a process which could generate vast energy by the release of neutrons, leaving relatively little radioactive waste. As deuterium is a common isotope found, for example, in sea-water, the promise of this remarkable facility is that, if it could be made to work effectively, it might solve the problems that the planet faces as a result of climate change produced by using fossil fuels.

The laser was invented just 50 years ago. When lasers were first considered nobody thought that they might help produce nuclear power. Nor, for that matter, did anybody envisage that the laser might be used as a barcode reader in a supermarket checkout, or in a CD or DVD player. Nobody foresaw that they might be used to recognise the base pairs of the DNA in a gene-sequencing machine or transmit messages by fibreoptic cable down the internet. Indeed, nobody anticipated that the laser might be used to measure distances, to act as like this pointer, or to be useful in refined surgery of the human eye. And certainly, nobody imagined that if we were able to focus the spot size produced by a laser down to a mere nanometer – a spot about two thousand times smaller than the smallest living organism on our planet - we might eventually produce a most powerful microscope capable of looking inside molecules, or make a tool for quantum computing and used for what seems to be an almost unbelievable capacity for vast memory storage.

Hardly surprisingly, this huge installation at Livermore, the National Ignition Facility, costs a great deal of money to run. When I asked Ed Moses, its Director, how he persuaded George W Bush (not the most science literate of American presidents) to spend $116 million at dollars annually on research into laser technology, he replied casually, "Well it's obvious, isn't it. This is part of our nuclear weapons program."

The laser is typical of most scientific developments. The impact of most advances is not fully recognized at first. When Madame and Pierre Curie refined pitchblende to produce uranium and discovered radium, nobody foresaw that the substance which sat glowing gently in the dark of their shed might be used eventually to cure cancers, or be used in mobile X-ray vehicles to give clinical information in the First World War. Nor did scientists recognize that radioactive substances might have devastating effects, or that their destructive properties might be used in human conflict.

The last fifty years has seen remarkable technological advances. The microchip, the magnetic resonance imaging machine, the contraceptive pill, and improved penicillin to make more effective antibiotics. Our ability to make transgenic animals has been vital in untangling the mysteries of genetics, and the technology of fertilising human eggs in a plastic dish helped childless couples to have babies. Each advance was only made possible by basic research and in none of these instances did the scientists foresee the huge potential of their work on the laboratory bench. In making a microchip, nobody foresaw the modern laptop computer or mobile phone. MRI was originally thought only suitable for assessing metals. It was two decades before people realised that penicillin was immensely powerful for treatment of so many infections. And in my own field, colleagues exploring embryology mostly thought that human IVF was an impossibility. And it is important that all these technologies contain a downside that was not recognized, either. Nobody saw that the ubiquitous microchip would lead to a loss of our privacy, that the contraceptive pill would result in many women leaving attempts at childbearing too late, or that the wide use of antibiotics might produce devastating resistant bacterial organisms.

Technology has always implied a blessing and a curse. In the British Museum, there is a marvellously worked pear-shaped flint-stone that was a handheld tool, possibly an axe. It comes from the cradle of mankind, the Olduvai Gorge in what is now Tanzania, where hominids originated. And there is another flint in the Museum, almost exactly the same size and shape as that from the Olduvai Gorge, but dated a mere 200,000 years old. It was excavated at Boxgrove, near Chichester. How extraordinary that, in over one million years human technology hardly progressed. Flint-stones are what separate us from all other animal species. When we developed them we changed our diet. We scavenged meat from dead animals and subsequently even hunted live ones. This change gave the lipids which helped to make the human brain, and the size of the human brain also increased because hunting required early pre-humans to work in groups and, of course, communicate. So in a sense, humans are the only species that have used tools to manipulate their own evolution. We might use tools again to manipulate our evolution – more of that later.

These changes meant that the brain expanded rapidly to produce the modern human. Four million years ago, Australopithecus afarensis, Lucy, had a small cranial capacity of about 450 mL; subsequently, Homo erectus doubled its brain to around 900 mL. Modern humans have a brain averaging about 1450 mL volume, but might I be permitted to observe that women have a brain size averaging about 70 mL less? Before some male members of my audience get excited, let me emphasise that women have a slightly smaller brain because they are prepared to ask directions about where they are going.

Homo sapiens has lived on this planet a short time in evolutionary terms - some 100,000 years. And the genes making up the human brain have not changed much. For a moment let us stretch an imaginary line across this Gothic chapel and pretend that it is a time-line representing the last hundred thousand years. Now let us draw another imaginary line between my two fingers – just over 40 cm - pretending this roughly represents the last 400 years. In that time, Hamlet was written, the spinning jenny invented, the steam engine manufactured, we built computers, landed on the moon and produced synthetic living organisms in the laboratory. When Shakespeare completed Hamlet in 1599, one could imagine him leaning over the parapet of London Bridge spitting into the Thames, musing that the scene around him was unlikely to change that much. There was a kind of certainty about human affairs - although William Shakespeare couldn't have expected the Globe theatre built by the Burbage Bros would burn down 16 years later as a result of a technological advance – the novelty of a large cannon on stage, a prop used during a performance of Henry VIII which set fire to the thatch in the roof. But nowadays, technology is moving so fast that we cannot predict the future. The human brain is made by the same genes, but the human mind expands exponentially.

As our technology becomes more inventive and powerful, we live longer healthier lives, are more fulfilled and almost certainly happier. But though a cause for optimism, the fact that we can no longer predict where technology might take us makes us feel threatened. Over the last 10 years or so there have been several crises in public confidence about science and technology. The House of Lords Select Committee recommended firm action regarding nuclear waste; yet 10 years later the government has taken no action; nuclear waste is still stored dangerously above ground. The débacle over BSE and CJD cost the UK around five billion pounds, and failure to take prompt action over foot and mouth epidemics some nine years ago decreased people's trust in the food they eat even more. Suspicion of genetically modified crops means UK scientists have been unable to do good field trials. Consequently, this technology cannot be developed when it might feed starving populations in the developing world. The massive, and some might say illiterate, response to human cloning was unhelpful - perhaps I may observe that there are around 24,000 human clones in Britain yet they do not disrupt the moral fabric of our society; they are, of course, identical twins. Aggression about animal experimentation has made it difficult to pursue. Yet such research, humanely done, is essential in promoting the health and well-being of both humans and animals. Failure of uptake of the MMR vaccine in many inner cities - such as Manchester, Liverpool and parts of London - risked an epidemic that might have killed many children; as it is, there are some children who are now brain-damaged unnecessarily. It is also fair to say that there will be many boys in our population who will be infertile later in life because they contracted mumps, an infection against which the triple vaccine is highly effective.

Why was there public mistrust of these technologies? There was a notable failure to listen seriously to public concerns, and so there was public pressure to discontinue their development. Of course, distrust of MMR was partly due to dishonest publication by a discredited scientist; and press comment, particularly in the Daily Mail, fuelled paranoia. But few people in the Department of Health, or in the medical and scientific community, understood that for a woman with a baby, her main concern was her baby's protection. This vaccine was not a treatment for a child already ill – it merely might prevent illness, but might also risk it. The best solution for a mother would be not to have her child vaccinated, but hope that everybody else in the population would - so that there would be little risk of the infection prevailing.

Technology has always had a downside. Some 11,000 years ago, people in the Middle East ceased hunter-gathering and the Fertile Crescent in Mesopotamia became the centre of some of the earliest farming settlements. But this new technology had a negative aspect. Male hunter-gatherers living in that region had an average height of 1.78 m, and females of around 1.65 metres. As agriculture grew, human height decreased. Many diseases became more prevalent and longevity shortened. Theya Molleson's excavated bones from Abu Hureyra near the River Euphrates show that although the general health of these settlers was not too bad, they often suffered extreme joint damage from the heavy work of carrying loads and grinding corn with querns, had rotten dentition with multiple dental abcesses, and deformities of the spine and legs. Farming also reduced genetic diversity – these people survived on einkorn wheat, lentils and barley – and it also made conflict over territorial disputes more likely. 7,000 years ago, Abu Hureyra was abandoned; we don't know why but perhaps farming made its inhabitants more vulnerable to climate change. Incidentally, farming is possibly the first technology which contributed to climate change. Methane, emitted from ruminating cattle, is over 20 times more effective in trapping heat in the atmosphere than carbon dioxide.

We think of farming as involving plants and domestic animals. Since earliest times, humans farmed fish. The book of Isaiah, chapter 19, mentions it, when the prophet points out there shall be mourning when the Nile becomes contaminated. Pieter Breughel the Elder's wonderful woodcut, dated 1556, "Die grossen Fische fressen die kleinen" (big fish eat little fish) illustrates an old Flemish proverb; here a father teaches his son that the powerful instinctively prey on the weak. This picture, derived from Hieronymus Bosch, is now in the Albertina Gallery in Vienna, and shows just how many fish are cannibals – in the bottom right-hand corner a small mussel is trying hard to ingest a much larger cod. Fish consuming other fish is highly relevant to modern aquaculture. Vast quantities of anchovies, whiting, sand eels and sardines are hoovered up to provide the diet of farmed fish. It can take 5 kg of small fry to produce 1 kg of good salmon on the table; some predatory farmed fish, such as tuna, require even more. Removing small fry from the ocean to maintain this industry probably increases the continued depletion of the world's stocks of wild fish. Krill are also at risk -- around 200,000 tonnes of these little crustaceans are used annually to feed stocked fish, which means less staple food for many whales, some sea mammals and many seabirds. So fish farming threatens not only of wild fish, but birds and coastal mammals as well.

Fish tend to be reared in extremely crowded conditions. Commonly, there may be over 62,000 fish in a one hectare area. Each fish, perhaps measuring around a metre in length, has less water than that in an average bathtub. Trout are stocked at even higher densities. They are generally reared in freshwater raceways or ponds with around 60 kg of fish per cubic meter of water; this is equivalent to 27 trout, each one foot long in one bathtub. So injury and disease are inevitable. The fish rub against each other and against their nets and cages, with trauma to their fins, scales and tails. This causes stress and leaves them prone to parasites and infections. Antibiotics are increasingly used to control these infections, but even so, up to one third of farmed fish die prematurely. Moreover, there is some evidence that some drugs used to counter infection enter the environment, so that the presence of these drugs in human food supplies may contribute to human antibiotic resistance.

Freshwater fish farms use vast quantities of water. Whilst most of this water is clean and returned to rivers, in some parts of the world, for example India, China, Africa and parts of south-east Asia, the use of scarce water for aquaculture is serious. In Thailand, clean water is in short supply. Approximately half of Thailand's shrimp ponds were once rice paddy fields but now some 1.3 billion cubic meters of contaminated effluent is discharged from shrimp ponds into coastal waters every year.

Farming in the open sea encourages environmental risks. Encircled fish swim closely together and are prone to sea lice, which burrow into their skin and produce thousands of larvae. These enter the ocean and may infect wild fish. Many wild Atlantic salmon in British Colombia have now become infected. There are claims that over 90% of the wild fish population is at risk. And farmed fish may escape into the environment. Philip Lymbery, an animal welfare consultant, claims that 411,000 salmon escaped from fish farms during the year 2000.

But one key problem is that the use of powerful technology makes overfishing likely. Ten years ago, Dr JA Hutchings and colleagues published an important research study in the journal Nature. They report that some 90 species of fish once common in the ocean may face extinction. These include herring, sprat, mackerel, cod, haddock, snapper, redfish, and plaice.

Moving from farms into cities made mankind's predicament worse in some ways. Infectious disease became even more prevalent as hygiene was an increasing problem and clean water supplies became more difficult to maintain. Probably, infant mortality grew - a situation that did not abate until quite recent times even in the so-called civilised Western world. One only has to read Jerry White's "London in the 19th Century" or Peter Ackroyd's "London: The Biography" to understand how appalling were our living conditions until very recently.

About 5,000 years ago some accountants in Iraq invented a seemingly innocuous technology. This advance, writing, one of our greatest and most valuable inventions also visited destruction. Writing started in Sumer, and Sumer possibly also saw the first book burning. Wars ravaged the country between about 4000 and 3,300 BCE, and there is plentiful archaeological evidence from the sites around the ancient city of Uruk of deliberate burning of tablets by soldiers. Censorship was common, and here we see the Royal inscription of King Shar-Kali-Shaari on green alabaster, where the name of the previous king, Naram Sin, has been erased and overwritten. Ishbi-Erra, Amorite King and despoiler of Ur in 2004 BC E claims in another tablet to have "having destroyed their city and annihilated their culture" – presumably by destruction of their written tablets. Archaeologists believe that as many as 100,000 written records were destroyed in the region of Sumer in this period. Here is the testimony of Tiglath-Pileser I, destroyer of Babylon, who claims to have obliterated the records from that great civilisation.

Throughout history, writing and books have been seen to be so dangerous, usually by a ruling power, that they have often been destroyed. Some notable examples are on this slide. My favourite example (if I might call it a favourite) is that of the scientific books of Hypatia of Alexandria. She was the extraordinary brilliant daughter of the philosopher Theon, and taught mathematics and geometry, conducted astronomical observations and is said to have invented the hydrometer to measure the density of liquids. Seneca Scholasticus, a Christian historian, said of her: "On account of the self possession and ease of manner which she had acquired in consequence of the cultivation of her mind she not infrequently appeared in public in presence of the magistrates. Neither did she feel abashed in going to an assembly of men". Unfortunately her forward behaviour outraged local Christians. The monks abducted her, beat her with tiles, cut out her tongue and pulled out her eyes. They quartered her body and burnt it together with her books. I have to admit that I'm attracted to the imaginative portrait painted by Charles William Mitchell in 1885, hanging in the Laing Gallery in Newcastle-upon-Tyne. It may not be surprising that this is one of the most frequently reproduced images on the internet.

The Internet is the modern extension of writing. It is free and is an extremely rapid way of retrieving data, receiving news, connecting with people, shopping, learning, and playing games. This giant lattice of millions of computer networks linked together with hundreds of millions of machines is a remarkable mesh. In less than 20 years, around 1.6 billion people have started to use the World Wide Web - nearly one quarter of the world's inhabitants. Free access to so much information makes it one of the greatest democratizing forces of all time. Yet, paradoxically, the Internet is one of the biggest threats to our democracy. The Internet transfers writing in such a way that the machine (and any person operating it) is usually quite unaware of the physical location of the computer at the other end. Moreover, the person using the Internet normally has little or no knowledge of the route through the web that his or her data is taking. It can therefore be intercepted without the user even knowing.

Perhaps the most important aspect of our digital revolution is its extensive global economic use, fundamentally changing the way banks, businesses and individuals make financial transactions. But very few of us understand exactly how this digital transfer works. Even if we use the web frequently most of us don't have the slightest inkling about its technicalities. We have a vague idea about our web browser, but we do not see the layers of technology beneath the surface. And just as the technology is largely invisible to internet users, so are the risks - which are profound. They threaten our security because we only have a very limited ability to control how information we have entered on our PCs or mobile telephones is used.

For example, we lose control of data about ourselves if our details are fed into a machine operated by business, a public service or the government.

In our digital economy, government can be remarkably careless about the information it stores on our behalf. Unbelievably the UK government lost the national insurance numbers of 17,000 citizens in 2008. In retrospect, it seems farcical that this digitally stored data was sent by routine post. If that were not enough, the Ministry of Justice lost information affecting more than 45,000 people, in some cases revealing their criminal records and credit histories. Details of 25 million child benefit claimants vanished last year, and the Home Office lost the personal details of 3,000 agricultural workers - including passport numbers when two CDs went missing in an envelope. In five separate cases, the Foreign Office mislaid information affecting about 190,000 people. And the Department for Transport misplaced personal data on six separate occasions, including 3 million records of driving test candidates in May 2007. One might reasonably expect that where national security is involved, officials would encourage particular care - yet the Ministry of Defence lost an unencrypted laptop computer containing 620,000 personal records, including bank account and national insurance numbers and information on 450,000 people named as referees or next of kin by would-be servicemen and women.

These breaches do not necessarily mean that these data will be used by unauthorised persons. But the potential for damage to the individuals concerned is substantial and long-lasting, ranging from financial losses to loss of reputation. Moreover, if when using a personal computer we have our identity stolen we may even be accused of crimes we didn't commit. Other risks undoubtedly include threats to personal safety and the potential for physical or psychological harm. One high profile threat is that posed to children.

Every computer connected to the Internet is identifiable with a unique number -its IP address. Messages or information are sent to the appropriate machines by machinery reading the destination IP address placed by the sender. Providing that an internet service provider cooperates it may be possible to trace an IP address, but unfortunately even this is very limited because a source machine may be used without permission - for example, in an Internet cafe, an airport lounge or a hotel. Equally, an unprotected wireless connection may be the source, for example, in a house where a computer is in range from the street. Commonly, the source will be an identifiable consumer's machine but one which is insecurely configured or is inadvertently running a malicious piggyback program. Tracing the true source of abusive content under these circumstances is complex and, usually, unsuccessful. And the internet threatens our democracy for another reason. It is unregulated, indeed to some extent unregulatable; it can convey entirely inaccurate information, sedition, pornography, violence, and promote terrorism.

Our understanding of genetics was one great advance of the 20th century. Yet the field of genetics has always been exploited. In 1915, an idealist young scientist, Andrei Vavilov, journeyed from Moscow to study with William Bateson in Cambridge. Bateson was one of the first scientists to understand the nature of the gene and greatly approved of Vavilov's warm, high-minded principles. During the next two years, his protégé came to understand that genetic science could help breed better plants to feed starving people in czarist Russia. But when Vavilov returned to Moscow to implement his ideas it was 1917, the Czar had abdicated and by October, Bolsheviks had seized power. For a while, Vavilov was allowed to pursue his studies; in the next few years, he traveled the world amassing a remarkable, unique collection of seeds – 250,000 different species from countries as far apart as Mongolia and Peru. This good, altruistic man became of the most respected scientists in the Soviet Union, elected a member of the Soviet Academy of Sciences and appointed Director of the important Institute of Plant Breeding. In

1926 he received the highest honour - the order of Lenin. With his knowledge of genetics, inspired by Mendel and Bateson's teaching, and with his vast collection of seeds painstakingly gleaned from across the globe, Vavilov was in prime position to do what farmers have attempted since the beginning of recorded history - to hybridise and breed prolific, fertile crops that would inherit hardy characteristics. Here was the opportunity to improve the lot of peasants and alleviate the hunger ravaging the USSR.

The sinister figure of Trophim Lysenko now enters our story. From peasant stock and poorly educated, this vindictive and deeply unpleasant man was the antithesis of the highly idealistic, kindly Vavilov. He trained in plant husbandry, and was a junior technician in a remote agricultural station in Azerbaijan. By chance, a local journalist published a glowing report of his work. Seemingly, some of his peas had survived a particularly harsh winter to provide a valuable crop. Here was good political capital that was noted by a more important newspaper, Pravda: a 'barefoot scientist' who was not dithering around with esoteric academic matters but addressing practical problems. This 'admirable young man' didn't trouble with chromosomes (he denied their existence) or irrelevant studies of fruit flies, but could make the desert fertile.

Pravda's report was classic Marxist thinking, ridiculing members of the intelligentsia like Vavilov, who were too absorbed in a high-flown irrelevant study of no use to the proletariat. Lysenko claimed that freezing seeds made them hardy when they germinated and that this valuable characteristic was passed on to subsequent generations. So-called "acquired characteristics" had been proposed by John-Baptiste Lamark about 100 years earlier. But Lamark had been completely discredited with knowledge of the new genetics. Vavilov was very supportive of Lysenko but on repeating his work he could not confirm freezing was beneficial. Yet the Kremlin was delighted that a peasant had made an important discovery. Stalin was collectivizing Soviet agriculture and needed all help that science offered. By the end of 1929 the world was in financial chaos, Wall Street crashed and Stalin had ambitions to make the USSR the truly pre-eminent global power. Science was the driver of his new economy so he determined to bend nature to his will. In modernising agriculture still run on mediaeval lines, Stalin ignored the advice of experts like Vavilov and promoted Lysenko.

In Kazakhstan alone, one million peasants starved when Lysenko's manipulated harvest failed. In Ukraine, the situation was more horrific and Stalin's reforms there, supported by Lysenko, resulted in the death of at least five million landholding peasant farmers, the Kulaks. Yet Lysenko was increasingly given resources. Scientists who disagreed with him, and therefore Stalin's policy, were dismissed, purged or arrested. Eventually, Vavilov was sent by the State on a phoney mission to the Ukraine and when out of contact with colleagues in Moscow, abducted by the Secret Police, OGPU, and imprisoned. Lysenko had denounced him. Not even his wife or children knew where he was. Andrei Vavilov was repeatedly tortured in prison, dying there, ironically of starvation.

This sad story touches themes running through this lecture. Governments do not always use science wisely. And when a technology fails, the result can be catastrophic. Oddly, there is also the question of so-called "scientific truth". Although the ideas of Lamark have long been regarded as totally wrong, it turns out that modern genetic research suggests that organisms may occasionally change in response to their environment and that these changes can be inherited. Some traits exhibited by offspring are present because of parental experience even though the actual letters of the DNA had not been changed.

The USSR was not the only country to misuse genetics. The eugenic movement started in Britain when Francis Galton, Darwin's cousin, argued that we should encourage intelligent, strong and able people to breed, but not those with a 'defective' inheritance - such as the poor, the tubercular, the feeble-minded and those out of work. The movement gained considerable support in the USA in the 1920s, when a number of States enacted laws against misgenation – here is the preamble of a bill to prevent intercourse between blacks and whites, only repealed in 1967. Harry Laughlin, a scientist at Cold Spring Harbor Laboratory –one of the great genetics institutes in the USA, was appointed by the US Secretary of State to be in charge of screening potential immigrants to see if they were genetically 'desirable'. He was given an honorary degree by the University of Heidelberg, in Nazi Germany in 1936.

The Nazis, of course, espoused eugenics to promote the Aryan race – here is Kramer, the camp commandant at Auschwitz with the handsome Dr Mengele who was so gripped by studies on twins, converting healthy children into skeletons – if they survived at all. But even after the war, the eugenic movement continued – in Sweden more women were sterilized without consent because of some perceived genetic unsuitability than before 1939. And this drawing from the Carnegie Institute in the USA from 1952 shows how one scientist set out to prove that Blacks (or negros) were genetically different to Whites. In his drawing of what he claims to have seen under the microscope he demonstrates a lack of objectivity, and a misuse of science to prove a flawed idea.

We scientists are as fallible as any other human. Sometimes what we see down the microscope is so remarkable that we get carried away and lose a proper sense of reality. Look at this remarkable photograph taken in Michael Schneider's laboratory in Imperial College London. He has taken a human embryonic cell and chemically manipulated to that it has developed into a beating heart cell, a cardiomyocyte. There are about 600 people in this Chapel; given that well over 200 of you may develop heart disease as you age, who could not be overwhelmed by the promise that cells like this, grown in the laboratory, might be used to mend damaged heart muscle. Of course, this technology may be possible in time, but the loss of objectivity and the risk of making exaggerated claims about what we have done is ever present.

A classic example is seen with some work done in my own laboratory many years ago. This film clip shows the removal of a single cell from a human embryo. The mother had lost a child age three some years earlier from a severe genetic illness. So we set out to screen all her fertilized eggs like this by analysis of the DNA – to see which did not carry this fatal genetic trait. The result was the birth of these twins – now aged 20 – called perfect babies or designer babies by various journalists when they were born. They are not perfect – apart from the blemish on little Lisa's chin caused by a fall seven hours before the photo was taken. They are not in any way designed – the only measurable difference between them and their elder brother who died from his disease is a single letter of the three billion letters of their DNA alphabet. They merely did not carry a defective copy of one particular gene.

But this did inhibit Dr Lodish, of MIT and Rockefeller University, one of the world's leading molecular biologists. He wrote of our work in the leading journal Science……. It is very flattering that an esteemed colleague might think what Alan Handyside, my colleague, and I did was that important, but it is a gross exaggeration. I now feel that DNA diagnosis in embryos a minor and relatively unimportant invention.

If I were to ask this audience what was the most important advance in biology in the last 30 years, I suspect many would suggest the sequencing of the human genome. When the complete sequence was finally published, Michael Dexter the Director of the Wellcome Trust funding some of this research, claimed that it was more important 'than the invention of the wheel'. And President Clinton stated that this advance would 'tell us more about our humanity' than any previous invention. But the genome is a wheel that hasn't turned very much so far. And possibly, a study of the 1599 version of Hamlet tells us much more about our humanity than the sequence of our DNA alphabet.

Eight or so years since the genome was published, our individual genome tells us surprisingly little about the chance of getting common diseases such as heart disease or diabetes. Yet private companies exploit people's fears and sell individual gene sequencing. At present, this knowledge is largely useless. And sadly, so far, the human genome has not been particularly helpful in the diagnosis or treatment of most diseases, except a few rather rare ones. Knowledge of the genome seems promising in the treatment of some cancers, and it may help drug design to meet the needs of some individual patients. But much-vaunted genomic medicine will be largely useless without vast investment in health services. For this information to be really valuable, we need huge improvements in computing and massive spending on informatics.  There would need to be restructuring and improvement of pathology services, and much training of health care workers. Such expense seems impossible at the present time. So what we have done by these rather exaggerated claims is to raise expectations that may come to haunt us.

Our ability to modify the genes of mice and make a so-called transgenic animal seems much more important. This gives us a dynamic way of examining what genes do, and what happens when a gene is missing, and how various genes are controlled. But as this technology becomes more sophisticated, it will carry risks. If we are able to manipulate the genes of a mammal effectively, we may be tempted in time to try to enhance humans. We already know of certain genes that seem to be associated with improved cognitive ability. There are other genes which may enhance muscular strength and it is just possible that there may be a genetic basis for our longevity. So genetic manipulation presents the most serious ethical challenge. If we were able to enhance humans to make superhumans, what value would be given to mere human life at some point in the future?

In the last three weeks, the experiment done by Craig Venter and his colleagues in making the world's first synthetic life form received huge publicity. After various false starts, he has produced a rather insignificant bacterium, a species of mycoplasma. As it seems to be able to replicate this appears to prove that it is alive. What Venter and his team did was to make small chunks of its DNA and glue them together in a borrowed bacterial cell. The total length of the genome of this organism is only just over 1 million base pairs, so it is smaller even than many genes in human body. For example, the gene which produces dystrophin, which makes muscle in our arms and legs, is well over twice as big. So it seems very unlikely that a synthetic organism which had any kind of nervous system, could be made in the foreseeable future. It may be creating life, but it is excessively simple and without consciousness. In any case, no scientist has yet made an artificial cell. So Doctor Venter has not cracked the key obstacle to creating life because his experiments required a borrowed, empty cell from another organism. Critics complain that he is playing God. Yet I am not so sure that playing God is necessarily a bad thing.  Many believe we are endowed, after all, with a God-given intelligence which we need to use for good rather than evil. When we take an antibiotic, we save a life by playing God - we literally subvert nature – but surely, this is highly commendable?

A more serious criticism is that an artificial organism might escape into the environment and cause havoc with the human immune system, which might have no protection against it. But this doesn't seem a genuinely serious risk, as we manipulate bacteria every hospital laboratory under strict controls every day. Many of these bacteria are extremely pathogenic and dangerous. Routine containment of a bacterium like this should be no different in any respect.

Why would anyone want to make a synthetic organism? Jay Keasling at the University of California at Berkeley has manufactured bacteria which might synthesise the drug, artemesinin. The chemicals from which this expensive drug is made are found in the leaves of the wormwood plant. A synthetic organism, it is claimed, might make this drug much more cheaply. As artemesinin is valuable in the treatment of drug-resistant malaria, this advance might help people in poorer parts of the world where the malaria parasite is common. Man-made bacteria might be useful in other ways. Some bacteria are anaerobic and use carbon dioxide; theoretically, banks of suitable bacteria in culture might absorb $CO_2$ from the atmosphere to control greenhouse gases. And other bacteria make hydrocarbons so in time we may make diesel fuel using synthetic bacteria. But the best reason for research in synthetic biology is to improve understanding of the mechanisms which control cells and their growth. During his experiment Venter discovered a gene sequence which controls chromosomes - this kind of discovery could be very important in human medicine.

At present, the crisis in the Gulf of Mexico is in the news. The production of oil has changed human aspirations and activity more than any other technology. We drilled for oil for more than 160 years, and it was recognized over a century ago that capping an oil gusher can present horrendous difficulties even when at ground level. Various environmental disasters occurred over the last century as a result of such leakage. This school in Rusk County, Texas (not so far from the Gulf) blew up over 70 years ago – killing 298 children with their teachers. So it seems extraordinary that nobody appears to have appreciated how serious and potentially risky is drilling oil over one mile below the surface of the sea. President Obama conveniently blames the company, BP for this shocking environmental disaster, but it was a matter of chance that it happened with BP's activity, as this blow-out could have been caused by any oil company at some point in time. Is not greed for cheap energy the real source of this catastrophe?

I would rather live in 2010, than 1910, 1810 or 1710. The benefits of human inventiveness have never been greater, and we have many reasons to be optimistic about the future. But we must accept that the threats now facing humanity as a result of our cleverness have probably never be more serious. If our ingenuity as a species is to continue to bring great benefit, and if the dangers latent in nearly every technology are to be minimized, we need to take greater care in how we handle our knowledge.

The great majority of scientists firmly believe that they are likely to bring benefits to other humans and to the planet. Like most humans, we want to do good. But the pursuit of science is not always easy; it requires mental discipline, training, it is usually not particularly well rewarded financially, and it is lonely, often requiring long periods of tedious work. Most research scientists live on their wits and it is not a particularly secure profession. These difficulties may sometimes lead to quite intellectually aggressive attitudes. Unfortunately, because science courses at university are so packed with information ethical issues are not routinely taught in most universities to science undergraduates - except those studying medicine.

Scientists are not generally responsible for the misuse of the knowledge they generate. To a large extent for the public are answerable to how science is used. If we benefit from scientific progress, then we all must understand that we have a duty to learn more about science so that we can exercise an effective voice in how it is used and be aware of the implications if it is misused. The obligation to use scientific knowledge wisely cannot be met without the widest involvement of society.

Wisdom requires knowledge. So there is a pressing need for as many people as possible to be scientifically literate. Otherwise it will be difficult for citizens to take wise decisions and their political representatives and policymakers to make good choices. Science should be seen as an important part of human culture in a civilised society there is an obligation for everybody to understand more about science and to recognise that ignorance is unacceptable.

So every society needs to ensure that the scientific education provides is of the highest quality. Governments need to reflect on a current trend and question whether investing in science education simply because it is valuable to the economy is sound policy. Rather, they should consider investment in science education vital because it is the best way of ensuring that we, our children and grandchildren will live in a safer and healthier society.

In being more science literate, we might consider that the announcement of a new discovery is almost is heralded by exaggerated claims for its immediate value, that many technological advances have a threatening aspect which is not usually recognised at the time of the invention, that most human advances have beneficial applications which are not envisaged when the discovery is first made and that many really important discoveries are arrived at by serendipity.

May I end with a manifesto which is certainly not the result of any coalition?

1. Scientists should try to communicate their work as effectively as possible because ultimately it is done in behalf of society and its adverse consequence may affect us all.
2. Communication is a two-way process. Good engagement with the public involves not nearly imparting information, but listening to and responding to the ideas, questions, hopes, and concerns the public may have.
3. We need recognise that the science we do is not entirely our property. Whether the taxpayer helps fund our education or not, most of our training and research is financed by taxpayers, in grants from research councils or by charities. The public has a major stake in what we do.
4. The media play a key role in how the public learn about science; so we need to share our work more effectively by being as clear and intelligible as possible and not exaggerate the potential of what we are doing
5. We should consider the ethical problems which may be raised by the application of our work.
6. We should reflect that science is not simply 'the truth' but a version of it. A scientific experiment may well prove something which may change with the passage of time as we gain a better understanding. Science is not absolute, being often about uncertainty. When we express certainty, it may be dangerous.
7. We may be immensely proud of we discover but should not adopt a culture of assumed omnipotent or arrogant assertion. Arrogance is likely to damage the reputation of science by increasing public mistrust.
8. We should see our science in a broad context and should be cautious about making predictions about the future, as unrealistic expectations may be damaging.
9. Governments whether totalitarian, oligarchic or democratic, usually have vested interests which are not necessarily conducive to the good use of the fruits of knowledge. We need retain some independence from politicians and should not avoid criticising their decisions when if we feel they are wrong.
10. Commercial interests so often promoted by governments and universities cannot be disregarded if technology is to be exploited for public good. But scientists need to be aware of the dangers of conflicts of interests. The history of science shows that the pursuit of commercial interests can lead to the loss of public confidence.

11. Most of our best basic science is done in universities, but universities tend to seem elite and mysterious and are sometimes perceived as rather threatening to ordinary people. Those of us working in universities must foster a new culture of open access to our institutions where they can help to strengthen activities that involve community service and outreach.
12. Schools have a vital role in encouraging young people to see the magnificence of the natural world. But many schools discourage children from appreciating the wonders of science, so we must try to support initiatives that promote more practical and experimental work, and show our appreciation of inspirational teachers. We should foster stronger connections between schools, school children and universities.

May I end by observing that a generation ago the mark of a civilised person was an appreciation of Shakespeare, Goethe, Thucydides, Rembrandt and Beethoven. But the pursuit of science has become so demanding that today's scientists are more likely to neglect their cultural inheritance. We might reflect that, by broadening our own interests, we may help non-scientists see science as part of our culture. Shakespeare or Montaigne may not be directly relevant to our research, but the cultural values they represent are universal and important. Perhaps the words of the Roman poet Terence may seem relevant: *"Homo sum: humani nil a me alienum puto."* "I am of mankind; nothing human is foreign to me."

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