Notes

1 The views expressed in this chapter are solely those of its author.
2 Latour attempts to reconnect the social and natural worlds by arguing that the modernist distinction between nature and culture never existed. He claims we must rework our thinking to conceive of a "Parliament of Things" wherein natural phenomena, social phenomena, and the discourse about them are not seen as separate objects to be studied by specialists, but as hybrids made and scrutinized by the public interaction of people, things, and concepts.

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17

SCIENCE COMMUNICATION

The Consequences of Being Human

Chris Bryant

Introduction

In the past, many scientists chose their profession because they were more adept in dealing with ideas and facts than with the unpredictable ferment of human relations. Communication, other than with their scientific peers, did not have a high priority: indeed, it was often actively avoided. The resulting lack of empathy with the general public led them into many false assumptions—'they're not interested', 'they wouldn't understand' and, by way of contrast and in the words of one eminent scientist passionately advocating immunisation, 'Show them the figures—how can they *fail* to understand?' How, indeed? It is the role of the science communicator to explain to the scientist how 'they' can fail to understand and, to the community, what the scientist meant.

Humans are remarkable for their consciousness; for their ability to reason, their self-awareness, their capacity for empathy, for remembering the past, awareness of their environment and, above all, to make choices from among many possible 'futures'. In the 21st century, the availability of information from myriad sources to inform those choices is unsurpassed. Increasingly, people are becoming connected to friends, neighbours, and workmates all over the world. They access information about government, the stock market and multinational corporations. They access scientific and medical information, not only from web pages designed for general use but directly, from scientific and medical journals. They establish specialist websites to facilitate the exchange of information and opinion. They Google, they blog, they tweet, they subscribe to Facebook and YouTube. They have mobile phones and other devices so that they can communicate on the way to work, or during lunchbreak, or on the beach, or climbing mountains. Never before have so many people become connected by the invisible strings of modern technology. This connectivity and the consequent complexity that it creates is a critical attribute of modern communication, accelerating the development of higher organisational structures (Westwood & Clegg, 2003).

Here is a definition. *Connectivity* is the state, property or degree of being interconnected (Frazer, 2003). One important consequence of connectivity is the emergence of order, beautifully illustrated by Kauffman (1995). He describes a thought-experiment.

> Imagine a scatter of similar buttons on a flat surface, distributed so that no button is touching another. Select randomly two buttons and join them with a thread. Repeat the process. For the first few tries, it is unlikely that you will pick a pair of buttons that have already been joined. As more and more buttons are joined it becomes increasingly likely that at the next try you will pick up an unjoined button and one that has already been joined to another. By connecting the unjoined button to one of the two already connected you create a string of three buttons. Continue this experiment and eventually each button you select will be attached to several other buttons. Networks form. If you plot the size of the largest cluster of buttons against the ratio of the number of threads to the number of buttons at each step you obtain a sigmoid curve (Figure 17.1). The scattering of buttons has moved, quite rapidly, from one level of organization to another. The process of stringing clusters of buttons together, and clusters of clusters leads, given an inexhaustible supply of buttons and string, to higher and higher levels of organization.

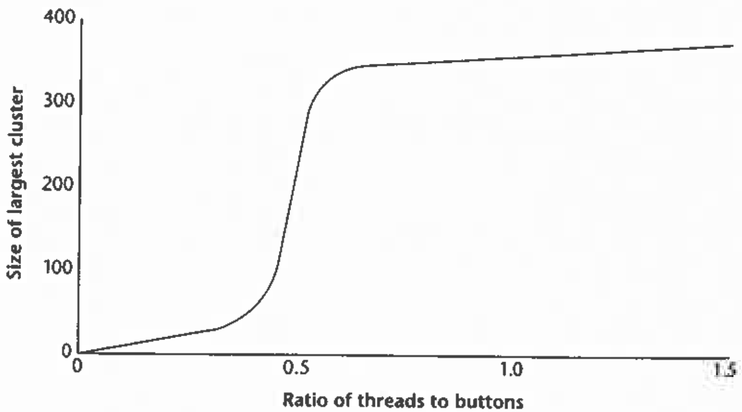

FIGURE 17.1 Clustering of Connected Buttons (*Source:* Kauffman, 1995, p.57)

Emergent Phenomena

Kauffman (1995), and others (eg. Waldrop, 1992; Boal, Hunt & Jaros, 2003) extend this analogy to a wide range of disciplines. The idea of 'order for free' is that repetition of simple processes creates complexity. This is an especially important idea for biologists. For example, the cells of an embryo responding over and over again to a simple repetitive series of 'commands' create a fully organised foetus.

Another and even better example is that of organic evolution itself (Chamberlin, 2009). Over the course of three billion years matter has organised itself into a system of the utmost complexity by the repetition of the simple imperatives of natural selection. Morphological and physiological innovations arise and each time there are consequences—emergent properties explicable with hindsight but not predictable - that enable the innovation to extend its geographical and physiological ranges. Then another innovation is selected and the process recurs. This chapter explores that process and examines some of the consequences for humanity, and the degree to which they influence understanding of natural phenomena (see, for example, Corning, 2008).

This process of simple, self-repeating events indefinitely continued—iteration—is at the heart of evolution by natural selection (Bird, 2003). Assembly of macromolecules according to simple rules led to the emergence of protocells. Protocells became the first prokaryotic cells, represented today by bacteria and blue green algae. Prokaryotes entered into associations to give nucleated 'eukaryotic' cells (Margulis, 1970). Each eukaryotic cell is thus the product of symbiosis, of connectivity between at least three prokaryotes and sometimes more. This is the type of cell from which all animals, plants and fungi are constructed. In the next stage, eukaryotic cells aggregated to become coordinated colonies of identical cells acting in unison (as in the alga *Volvox*). Assigning different tasks to cells within the colonies permitted higher levels of organisation. This stage is represented in modern sponges, which can be separated into individual cells of different types that subsequently recombine if left alone. Such division of labour became more or less permanent, as in *Trichoplax*, a small multicellular cellular mat with only three different sorts of cooperating cells. Finally, the permanent differentiation of cells into tissues occurred, as in all modern animals, plants and fungi—and humans.

This magnificently inadequate description of the origin and evolution of life shows only a few of the major events but illustrates another important phenomenon. Each successful step, each increase in connectivity gives rise to a population explosion followed by adaptive radiation into all available ecological niches, creating possibilities of life unavailable to precursors. Connectivity between units brings with it unforeseeable consequences. These 'emergent properties' are characteristic of life at each level of organization.

The idea that 'the whole is more than the sum of the parts' is widely attributed to Aristotle (384–322BC). The attribution is often made with reference to Greek theatre, to make the point that the whole play has integrity and makes an impact on the audience that is independent of the contribution of any one of its characters. This metaphor illustrates the concept of emergent properties. They are the properties of complex systems, whose complexity is the consequence of many simple interactions, but such that the behaviour of the whole cannot be predicted on the basis of the behaviours of the individual components.

When the three or more prokaryote precursors came together to produce a eukaryote cell, they created an entity whose potential (emergent properties) far exceeded the potential of the precursors, even taken together (Macklem, 2008). These emergent properties include the rest of the biosphere. They include human beings who form families, villages, towns, cities and nations. Humans cooperate in technology and together are on the verge of producing artificial intelligence, an evolutionary leap that changes the very nature of evolution. This has been made possible because, in order to survive, they shared resources and cooperated in buying and selling goods. From that emerged an entity called a 'market' that, in the whole, has properties and consequences that are unpredictable on the basis of the behaviour of the individuals who participate in it.

The evolution of neural systems underwent the same sort of process. All members of the 'single-celled' Protista show responsiveness to stimuli. In the multicellular Cnidaria, to which *Hydra*, jellyfish and sea anemones belong, responsiveness has, however, become largely the role of specialised cells called neurons. *Hydra* has only a simple neural network, yet is capable of such complicated behaviours as somersaulting. As Cnidaria become larger and more complex, many more neurons are needed to form large numbers of interneuron connections. The neural network of jellyfish is organised into a conducting nerve ring around the rim of the bell to control contractions. The next evolutionary step is represented in the flatworm, *Planaria*. It possesses two eyespots, each of which is associated with a ganglion, a knot of interconnected nerve cells, and from each of which a nerve runs backwards to the tail. This simple type of nervous system is greatly developed in all higher animals; many sense organs are concentrated at the front end because it is an advantage to have advance information about what you are getting into, and their associated clusters of ganglions multiply and become brains.

The vertebrate brain is the product of vastly increased connectivity. It culminates in the giant brain of modern humans, an enlargement that started with the modest brain of an ape a mere two million years ago. Connectivity is hugely extensive in the adult brain, one estimate putting the number of neurons at 100 billion, implying interneuron connections well into the trillions. As remarked earlier, the outstanding emergent property of the human brain is consciousness. This is not the place for a philosophical discussion of consciousness (for this, see Chalmers, 1996, 2010a) but it is, however, appropriate to consider some of its attributes.

Some Attributes of Consciousness

Awareness of 'self' is amongst the most important characteristics in the suite of adaptations to the environment provided by consciousness. Awareness of 'self', and knowing the boundaries where 'self' ends and the environment begins, implies awareness of other components of the environment and the ability to deal with its challenges.

Awareness of the environment is of obvious adaptive advantage. Unfortunately, the environment is potentially dangerous, so the downside is fear. An extension of the awareness of self creates an environment comprising potentially dangerous things that are 'not self'. Rocks and trees and bushes are perceived to have their own spirits: spirits that must be appeased, made harmless. The human capacity for visual patterning, to see faces in the fire, in clouds, or in foliage, leads first to animism, then deism, and finally structured religion. This basic human response to the environment creates problems for science communicators, who may find themselves confronted by religious sects claiming that meddling with nature is against God's laws.

There is a downside to the awareness of self that we call selfishness. Once the concept of 'my environment' becomes 'this territory is mine', there follows an instinctive desire to protect it. Another example of selfish behaviour is the reliance of selfish people on 'herd immunity' for keeping themselves and their families disease-free. They argue that others can incur the minimal risks involved in vaccination. This works in the short term as long as the great majority of people accept vaccination. As more people become complacent and refuse vaccination, the strategy fails, as the reappearance of formerly common infectious diseases in the First World has shown.

The ability to imagine what another person is feeling and adjust decisions and behaviour accordingly is known as empathy. It is an extension of the awareness of self to include an awareness of others. Of extraordinary survival value in small societies, where future options are limited, unfortunately it becomes qualified in large societies. Thus, an instinct to form a cooperative pack or herd or family group, which is of obvious survival value, leads to a more sinister outcome as populations become larger. It leads to attitudes such as 'it's my family against that one in the next valley' bolstered by spurious reasons, such as, 'they are not like us—their skin is the wrong colour' or 'they have the wrong shaped eyes'. This is the road to doing away with all those who are 'not like us', to cruelty, sadism, racism, nationalism, war, and genocide.

In communities with large numbers of people, the empathic faculty becomes attenuated, strong for family and friends, but progressively weaker for people who live in the next street, or town or another country. If this were not so, ordinary men and women who would balk at hitting another person over the head with a club could not bring themselves to drop a bomb they know may kill a hundred people.

Consciousness offers a way of 'seeing into the future' that confers enormous survival value. Every organism can 'see' a little way into the future. Enzymes in bacteria are produced when they detect a few molecules of useful food substrate. The bacteria then move up the concentration gradient to the source. The roots of plants actively grow towards water and nutrients, 'confident' of a good outcome. These are statistically valid responses, encoded in their genes. They are the end product of many trials in which the many bad outcomes did not lead to survival.

Most organisms on Earth manage very well without consciousness. Plants have a very narrow range of options and do not need consciousness to enable them to 'choose'; this is provided by various physiological responses, such as geo- or phototaxis. Animals, possessing the capacity to move from place to place, have a larger range of options; if they pick the wrong one, survival is compromised. While humans spend more than half their time self-aware, other vertebrates seem to run on 'automatic pilot', with brief flashes of self-awareness in circumstances of, say, danger. This, in humans, is like travelling along a very familiar path. For example, one's conscious mind might be grappling with a knotty problem and becomes so engrossed in it that it is with some surprise that one finds one has arrived at one's destination. Lower order brain function has taken care of what might have been quite a complicated journey.

Humans, however, can visualise numerous possibilities, options that offer a large range of outcomes that vary from 'very good' to 'disastrous'. Setting aside potential winners of the Darwin Award whose disastrous choices are likely to remove them from the human gene pool, most people select from a range of choices from 'good' to 'not so good'. There are far more 'not so good' options than 'good ones', and far more 'not so good' choosers than 'good' choosers. 'Not so good' outcomes therefore, are more likely to be chosen. This has important consequences for science communication. The sheer complexity of modern society created by billions of people has also created an enormous range of future options of the 'not so good but not disastrous' category.

Ability to make choices about the future follows the same rules as other biological phenomena, and conforms to a normal distribution curve. Those in the population who are able to make 'good' decisions (and for science communicators 'good' means based on sound scientific understanding) will occupy one small tail, while the 'not so good' deciders will occupy the huge hump clustering around the mean. The other tail is occupied by the 'disastrous' choosers. Given that the population of Earth is 7 billion, that hump will comprise huge numbers of people, most of whom will be intelligent, and many of whom will be influential and may have an interest in promulgating 'not so good' scenarios.

If one accepts the evidence for evolution, one must also accept the fact that humans are adapted to living on Earth. 'Adaptedness' may be defined as the best available fit to the environment—it is what is possible but is not necessarily either maximal or optimal. Rabbits did better when they got to Australia than in their native Spain. A camel is better adapted to living in the desert than to life above the Arctic Circle. It presumably feels more comfortable in the desert, whereas prolonged exposure on an ice shelf will lead to the supreme discomfort of dying. It is, however, possible that there is an ideal camel environment somewhere on Earth that is empty of camels because camels have never been in a geographical position to discover it; but, almost certainly, something else has.

Animals—and humans—do the best they can with what they've got. Life is a series of approximate fits, and they are always chasing 'adaptedness' because, inevitably, the environment changes around them. This is called 'Running the Red Queen's Race' (Van Valen, 1973) because, as the Red Queen said to Alice in *Through the Looking Glass*, "... it takes all the running you can do to keep in the same place." Beauty, comfort, and contentment can be considered to be personal measures of adaptation in humans, a sense that things are 'right'. But things continually change (both within and without) so 'nostalgia', for things as they used to be, especially for childhood things, is a common emotion that engenders resistance to change.

As the brain develops, and it gradually acquires self consciousness, it begins to observe first, its internal, corporeal environment and then its external environment. It needs this information to build a picture of itself and its place in the world. With it, it begins to assemble information about what is needed for survival. As it continues to develop, the brain makes hypotheses about the environment and tests them against what actually happens. It often takes the form of 'if I do this, such and such will happen.' If such and such does not happen the hypothesis will be weakened. If such and such happens, the hypothesis will be strengthened; successful repetition establishes it as a 'fact', *even if it is untrue*. It is an attempt to make sense of the environment in a way that will have a predictive quality that enhances survival. It can, of course, go badly wrong and end up in the form of meaningless ritual. 'I slew a black cockerel yesterday evening and the sun rose this morning' becomes 'I have to slay a black cockerel in the evening, otherwise the sun will not rise in the morning.' Cause and effect become confused; thus, belief systems are established as mixtures of truths and untruths. They may lead to conflict between communities, as in 'my belief system is truer than yours.' With the growth of larger and larger communities, belief systems progress from the personal to the collective.

Belief Systems and Science Communication

Belief systems are thus part of everyone's heritage. As we have seen in Chapter 9, 'belief' may refer to a principle accepted as true without supporting objective evidence, or it may mean a conviction based on such evidence. In the statement 'many believe that black cats bring good luck', the word takes the former meaning. In 'having considered all the evidence, the scientist believes evolution to be a fact' it is the latter meaning that is implied. Without carefully defining 'belief' it is impossible to have a useful discussion. In any event, the term describes an internal process that is extremely difficult for an outsider, such as a science communicator, to alter. At a lower level there are superstitions to which everyone is subject. In some cases they too can be unshakeable, especially in times of stress. Highly educated fighter pilots carry good-luck mascots; travellers carry St Christopher medallions for safety; unfortunates who descend into neurological disorder become enmeshed in a personal web of rituals that they must perform in a certain way; remnants like these weave a rich, dense fabric that is not easily penetrated by reason.

Entrenched beliefs abound in medicine and science. The placebo effect—the beneficial effect, say, of a sugar pill on someone who believes it to be a medicine - and its opposite, the nocebo effect, are now well established and the power of suggestion has to be reckoned with in modern pharmacopoeias. People are notoriously hard to shift away from their favourite nostrums, many of which can have no possible therapeutic effect but some of which occupy the uneasy hinterland of the marginally effective. There are nonsense palliatives such as rhinoceros horn, bear bile, and bat dung. Some years ago, however, I had occasion to go through an English translation of *A Barefoot Doctor's Manual* (translated by Fogarty, 1977) looking for specifics against parasitic disease and found no fewer than forty, amongst some hundreds of prescriptions, that would probably have some desirable effect. A great vindication of one Chinese medicine has been a new antimalarial derived from a daisy, *Artimisia*, concoctions of which have been used to treat the disease since at least 340AD (Klayman, 1985). Folk medicines characteristically have this mix of the effective and the magical. Science communicators find it notoriously hard to persuade people to jettison the magical. People tend to draw their own conclusions about modern medicine as well. Thus, the conclusion that, because antibiotics are brilliantly successful against bacterial infections, they must work against the common cold, is compounded of misunderstandings both about antibiotics and the common cold.

It is worth pointing out, however, that given a sufficiently large target audience, which will necessarily include people of many different beliefs, some groups will form coherent foci of opposition to attempts at science communication and will have an adverse effect on any measure of success that might be attempted.

Science Communication: Success or Failure?

One is justified in asking whether the possession of foresight in humans is a trait that confers biological success. It has certainly enabled us to pioneer and colonise more environments than any other biological species, though we tend to bring along our pets, pests, and parasites. It has allowed us to reduce infant mortality and to increase life expectancy to variable extents in different parts of the world. As a result, we have a population explosion; we are a monoculture that has become susceptible to epidemic diseases. Water is becoming scarce. We are using up other non-renewable resources at a rapid rate. We are beginning to compete for them and, as we seem to be addicted to wars of varying ferocity, including nuclear, there are several bleak scenarios ahead of us. Science surely has a role in helping to avert potential disasters. Science communicators have a role in helping the world community to understand the problems and the possible solutions but only, it seems, with limited success at present. But how does one measure success?

There are two measures that might be used to determine the success of science communication. The first is the time taken for the public to embrace a particular issue: the shorter the time, the more effective the communication. The second is the proportion of the target population that accepts a scientific idea: the greater the proportion, the greater the effectiveness.

Take, for example, the acceptance of evolution by natural selection. By any standards this has been a successful piece of science communication, one that has had a huge impact on society. Darwin published *The Origin of Species* in 1859. A majority of scientists and the educated elite had accepted it by the turn of the century, but there were still professional enclaves who remained sceptical. Even in the social revolution that took place after WW1, there were still scientists who rejected it.

After Huxley published *The Modern Synthesis* in 1942, it was possible to say that the *vast* majority of scientists were evolutionists, as were most non-scientists who were familiar with the idea. But even today, when much of the underpinning of evolutionary theory is in place, evolution is not universally accepted. A 2006 survey of the USA, Japan, and 32 European countries administered 152 years after *The Origin of Species* was published (National Geographic News, 30 Oct. 2010) shows that only about a third of Americans accept the evolution of humans from lower animals. The UK and Japan each had about 80% acceptance; only Turkey ranked lower than the USA, with about 25%. About two thirds of all people surveyed agreed that evolution had taken place. Is this a success of science communication or a failure? Is the glass two-thirds full or one-third empty? The implication is that even the best science communication can never be 100% effective. Science communicators do not have a monopoly of intellect.

History is full of stories of the promulgation of scientific knowledge. Unfortunately, a clear demonstration that the idea is correct does not guarantee the immediate success of its communication. Aristotle (c384–322BC) deduced that the Earth was round on the basis of empirical data derived from the observation of eclipses. Eratosthenes (c276–195BC) determined its circumference with an accuracy of between 1% and 16%, depending on whether Egyptian or Attic stadia were used as yardstick. A practical demonstration by Columbus, 1700 years later, should have put the matter to rest, but there are still Flat Earthers.

When the Royal Society was established in 1660, the communication of its findings was considered to be of high priority by the members. They created two journals to serve this purpose—*Philosophical Transactions* and *Proceedings*. The target audience was a well-defined and educated elite, mainly members of the Society itself. As an exercise in the communication of science it was astonishingly successful, ushering in the Age of Enlightenment.

Individual discoveries—or re-discoveries—also shared this success: Edward Jenner (1796; vaccination), Ignaz Semmelweiss (1847; prevention of puerperal fever), Louis Pasteur (1862; germ theory), Joseph Lister (1867; antisepsis), Florence Nightingale (c1859; medical statistics and epidemiology) are some names from the nineteenth century that resound in the history of medicine.

More recently, the banning of smoking in Australia to prevent heart disease and lung cancer has engendered legislation to make smoking in public places illegal. The widely advertised *Slip, Slop, Slap* campaign (*Slip* on a shirt, *Slop* on sun blockout cream, and *Slap* on a hat) to prevent melanoma is a triumph, as a quick glance into the schoolyards at the pupils in broad-brimmed hats will testify. Unfortunately, a downside is emerging, as cases of vitamin D deficiency are on the rise. The discovery of a fly in the scientific ointment is commonplace and is seized on by those who wish to oppose any particular measure. The greater good becomes, for them, obscured by the lesser evil. The debate over the MMR vaccine (against measles, mumps and rubella) is a recent example, in which the antivaccination case was helped along by a fraudulent paper linking the vaccination with autism. More recently, unfortunately, a flawed flu vaccine has caused some morbidity amongst small children and has reinforced the antivaccinators (Godlee, 2011).

Medicine is clearly a special case. The examples in the previous paragraphs are about health, a subject in which any audience will have a vested and immediate interest. Nevertheless, the messages have been accepted by the overwhelming majority of people, surely a great measure of success. A significant minority, however, still reject them. There are still those who cluster in draughty doorways to smoke, others who are unwilling to accept the risks of vaccination for their children, still others who continue to tan themselves on beaches without effective sun-screens.

New Problems for Science Communicators

At the beginning of the twenty-first century, humans are enjoying yet another layer of connectivity, linking to one another via IT media, to add to their biological heritage. Kauffman's (1995) button thought-experiment is reenacted over and over again as unforeseen political consequences emerge, such as the fall of the Berlin Wall and the turmoil in the Arab states (the 'Arab Spring'). People have greater access to information than at any time in the past, and that includes access to scientific information. They have access to the words and thoughts of scientists and to scientific journals. It is, for the most part, a good thing. The disadvantage, one that concerns scientists and science communicators, is that the conclusions that are drawn by people who do not have the benefit of a

background in science may be based on misunderstandings—or rather, they may interpret science in a way that does not conform with the view of the science communicator. It is difficult to argue with people who have as good, or greater, command of the facts, even if their understandings are flawed. The medical profession has always found this to be a nuisance.

Paramount among the misunderstandings is the concept of risk. Science communicators have great difficulty communicating the concept of risk. Risk for scientists, on the other hand, has a very firm basis in statistical theory and probability.

As we have seen in Chapter 6, failure of the general public to evaluate risk properly is compounded by their failure to understand the function of doubt and certainty in science. Science can progress by the gradual accretion of information until eventually the case for a given hypothesis is so strong that the great majority of scientists accept it. The theory of evolution discussed above is one such case. Another is plate tectonics. When I was an undergraduate in the 1950s, continental drift was an interesting but way-out idea that appeared to make sense of some knotty problems in zoogeography. Few scientists now would deny Wegener's (1912) hypothesis. But it was a hard-fought battle that polarized scientific opinion at the time.

Another way that science progresses is in leaps, in which the existing paradigm is rejected and a new one takes its place (Kuhn, 1962). For example, for twenty years biochemists sought a mythical seven-carbon acid that the then-current paradigm suggested was central to energy synthesis in cells. One biochemist, Peter Mitchell, rejected this idea and suggested instead that the mechanism involved pumping protons across cell membranes (Mitchell, 1966). Immediately there was internecine warfare among scientists but, within a surprisingly short time, Mitchell's view, for which he was awarded the Nobel prize, prevailed.

The public finds it very difficult to follow these sorts of arguments, where scientist is pitted against scientist, especially if they find themselves being invited to take sides. Realistically, nobody except the scientist is going to care much about proton pumping, or even plate tectonics. The current issue of climate change, however, provides a good example of the public bewilderment that can ensue when the current paradigm is hotly contested, as has been described in Chapter 13.

When there is debate about a hypothesis, the public feels that it is necessarily flawed. Vigorous debate is considered by the scientific community to be a strength of the scientific method, but is perceived by a section of the general public as weakening the position. In any large community, such as Australia, that section may also be large and vocal. The problem is compounded when the debate becomes politicized, thus entering an arena where majority opinions prevail as a matter of course, irrespective of the intrinsic merits of the issue. In such cases, the response from some sections of the public may be, 'if you can't defeat them, demonise them'.

At bottom, the climate change debate is about preserving for posterity the climate that humans have enjoyed for the last few hundred years. It is an example of a type of debate that has been going on among ecologists for decades. Are those bits of the environment that are sequestered for national parks then to be preserved in a pristine condition for posterity, or are they to be conserved, managed, manipulated within well-defined guide-lines for public use? It is a problem that is exacerbated by the short human life span. The ecology of the Earth is a story that is three billion years long: that of humanity is a niggardly two million years, while the luckiest of us will only see about one hundred. The Earth is about halfway through its life cycle and even a conservative estimate suggests that life has a further expectancy of about one billion years (Conway Morris, 2003). Life began more than two billion years ago. Cambrian organisms, including many that we can recognize as ancestral to modern forms, flourished about half a billion years ago. So there is plenty of time left for innovation and, unless humans sterilize the Earth, life will not have to start from scratch after a wholesale extinction. There is enough DNA in a handful of estuarine mud to populate a planet. Repopulation will not have to start from single-celled organisms either, as myriad multicellular beings live their lives in the refuge of sub-aqueous and sub-marine anoxic slime.

'Preservation of the environment' has become major catch-cry of modern times. Humans as individuals and collectively are anxious to preserve that one tiny cross-section of their present when they see that it is about to change. Sadly, change is inevitable. They also tend to put a human value on the environment, as if it is an actively nurturing entity. But as Lynn Margulis remarked:

> Gaia is a tough bitch—a system that has worked for over three billion years without people. This planet's surface and its atmosphere and its environment will continue to evolve long after people and prejudice are gone.
>
> *Quoted in Brockman (1995)*

Identifying with nature is not necessarily a bad thing but we should be clear about what it implies and about our motives. The Earth will continue to exist. It will not be 'our' Earth, any more than the Cambrian or Devonian Earths were ours. There has been an Earth without free oxygen, there has been an Earth with far higher concentrations of atmospheric carbon dioxide than any that humans have added or will add, and there has been a 'snowball Earth' with glaciation at the equator. There have been Earths flourishing in the aftermath of meteor strikes. Just as humans can look forward and see a profusion of possible futures, they can look back and see 'the one true past'—and if they don't like what they see they can edit it to conform to a more desirable narrative. The need for preservation and conservation has a basis in this nostalgia, a longing for things, persons, or situations of the past. It is an important human attribute, a by-product or consequence, in a conscious being, of adaptation to environment. A second attribute is a sense of posterity, the idea that the sacrosanctity of children extends beyond the immediate family to grandchildren and future generations. Both contribute to the perceived need to preserve the environment of the present, even though common sense tells us that the environment is continually changing.

It is a debate that has led to many notable confrontations within the community. It is an area of much dispute, even among scientists—and science communicators—who might legitimately take different positions because there are good cases to be made for both sides. In the end, it is a matter of personal choice, of opinion, and of emotion fuelled by different concepts of posterity. It is therefore a minefield for science communicators who themselves might come into conflict over the issues and contribute to the problem.

The biological implications of the ethical codes of religions resonate with the opponents of science. 'God made man in his own image' suggests that that image is holy and should not be tampered with. Issues like blood transfusion, organ transplants, and especially transplants between animals and humans engender considerable suspicion. Reproductive science is a particularly sensitive area. Positions on abortion are as much about religion as about conflicting ethical philosophies. *In vitro* fertilisation, implantation of embryos, in natural or in surrogate mothers, is both accepted and vilified. Science communicators can only make small gains against entrenched attitudes, as in all these cases the mood of public may descend into outrage. They may have to await generational change but it is important to remember that success achieved glacially is still success.

Genetic manipulation is an area fraught with perils for the science communicator. At bottom, the issue is about the usurping of god's prerogative. Mary Shelley's Frankenstein has reverberated among the anti-science lobby for almost 200 years, but builds on a substantial earlier history of the alchemist and 'mad scientist'. Frankenstein's monster escaped from the laboratory; so too could transgenic organisms. Inserting genes from one species into another is seen as violating the species barrier—notwithstanding the fact that it frequently occurs in nature—and possibly unleashing some future plague on humanity. Questions about the point at which a genetically manipulated tomato, say, becomes something else are important to the general public. 'How many animal genes' asks the vegetarian, 'do you insert into a tomato before it violates my convictions so I may not eat it?' That position does not change even when the vegetarian is informed that tomatoes and animals already have in common at least 30% of their genes.

'Unleashing the monster' is an opprobrium that also attaches to the peaceful use of atomic energy. As well as the tragic loss of life, measured in hundreds, due to reactor accidents, it is feared that radiation leakage into the environment may cause long-term pollution that threatens unborn children and posterity, thereby violating one of the most significant biological imperatives. Radiation exposure is thus another example of a malignant escape from control whose risks are magnified, in the minds of the community, well beyond reality. Conventional fuels have, since the Industrial Revolution, caused millions of deaths and even today, thousands die every year.

Stem cell research, in spite of the promises that are now gradually being fulfilled, got off on the wrong foot, because initially it used cells derived from discarded early human embryos and, later, from umbilical blood. This contravened two of the great biological imperatives, 'going against Nature' and, more important, the sanctity of children. Arguments that an early embryo is not, in fact, a child, are not considered relevant by many who point out that, at the very least, it is potentially a child. The sanctity of children extends to the perception of risk. Adults will accept a much higher personal risk than they will permit for their children.

This is particularly well illustrated by the vaccination of children. Vaccination is a difficult area where the sense of violation is as immediate as the needle-prick. A mother has to exercise willpower to allow this to happen. Instinctively, she wants to protect her child from the immediate discomfort, while, at the same time, intellectually, she understands that she is protecting it from a future and more dangerous peril. Unfortunately, when instinct and intellect come into conflict, instinct sometimes wins. It is therefore not surprising when a measure such as the MMR vaccine was promoted for the common good that some 20% of people rejected it. This has been either a very successful science communication phenomenon (80% vaccinated) or a failure (20% unvaccinated). It illustrates the very important need to identify the boundaries of success before embarking on any science communication program.

Failure to understand the range of opinions and abilities in a very large target audience has led many into error. Frazer (2003), in a study to determine why parents would not immunise their children in the face of abundant evidence of its benefits, adduced a remarkable fact. The non-immunisers were not, as supposed, ignorant and unschooled. Rather, they were highly intelligent with a high level of education, in some cases in the field of immunology. They were competent to understand figures and read graphs and yet they made, in the view of the scientists and science communicators, the 'not so good' decision. Arguments about maintaining 'herd immunity' had no impact. Their foresight, their view of alternative futures, led them to choose the much greater risk of subjecting their children to a potentially fatal childhood disease, rather than a vanishingly small one of side effects from immunisation.

New media have enabled such views to be propagated across countries and around the world, further compounding the problem.

Science Communication and the Internet

If you put the title of this section into your web browser you will get (January 2012) about 113 million hits, and 2 million from Google Scholar. Adding the

word 'blogs' attracts 68 million hits, and 'twitter' more than 21 million. About a year earlier, the figures were, respectively, 7 million, 2 million, 2 million, and 1 million. This illustrates, if illustration were needed, the extraordinary and continued growth of the internet, and its use as a medium for science communication.

A far-from-exhaustive scan of science blogs shows that they are often informative, interesting, but without the scientific rigour or credentials that one might find even in the more chatty science-based journals. Quite frequently one encounters writings that are at best journeyman pieces, earlier essays by young scientists who, presumably do not want this evidence of effort to be lost to posterity. In this it contributes to a general flaw of the internet. Much of the material has not been scrutinised by experts, so its quality varies. This is in contrast to one of the great strengths of science: peer review. Peer review has its shortcomings, but generally validates the integrity of the material that is published in scientific media.

Moon (2011) used *Twitter* as a device to highlight scientific issues that air on the internet. She found that she was able to correlate the immediacy of a scientific issue with the rate at which numbers of 'tweets' increased or decreased. Others are creating Twitter sites to encourage debate about science communication issues. For example, Kristin Alford launched a discussion in April 2011 entitled *#onsci: telling better science stories*. Over about an hour there were 395 tweets from 34 tweeters, and it became a 'trending topic' in Australia. The results were meagre; the consensus was that science stories should have strong narrative lines, rich in metaphor and symbolism. Any first-year text on science communication would make these points in the first chapter. Imagine, however, that this process was multiplied a million times, each iteration building on what had gone before ...

And so, with *Twitter* and *Facebook* and *Youtube* in mind, we return to Kaufmann's button experiment and 'order for free': for threads, substitute the Internet; for buttons, substitute people with personal computers.

Conclusion

This chapter has considered the roles that five attributes of consciousness—awareness of self, of others, of the future, of the past and of the environment—play in modifying the responses of the public to attempts at science communication. Consciousness is itself an emergent phenomenon, a result of increasing biological complexity, that is now adding another layer of complex interaction in the form of the developments of information technology.

The notion that organic evolution leads to complexity and that at each evolutionary stage there are emergent consequences, is of some antiquity (see, for example, Morgan, 1923). This is true for evolution of our own species. It has also been commonly believed that, as all natural processes are limited by thermodynamic principles, evolution is moving towards some end point. One endpoint was the 'sphere of human thought' or 'noosphere' of Teilhard de Chardin (1956):

> In the case of man … it is with … the appearance of the ability to reflect that we may link the whole cluster of the neo-properties that determine the formation of the noosphere.

Divested of its spiritual overtones, the notion that increases in biological complexity and connectivity are approaching some thermodynamically limiting endpoint has been embraced by many information scientists, who refer to it as a 'singularity' in evolution (Chalmers, 2010b). Observing that technological growth is exponential, Kurzweil (2005) adduced a law of accelerated returns that suggests that, in about thirty years, we will have arrived at a point where it exceeds that of the sum of human intelligence. According to James Martin (2007), a renowned futurologist, there will be a break in human evolution that will be caused by the staggering speed of technological advance. Human contribution to science will cease as technological development is taken over by artificial intelligence.

At that point, apparently, there will be no role for science communicators.

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