The Trouble with Science
Robin Dunbar

1 Introduction

p.1 His achievement was to discredit, once and for all, the long-cherished view that the earth is the centre of a universe whose sole purpose is the sustaining of human life. The world, he told us, is not always as it seems. Overnight, we humans became bit-part players in a drama whose stage dwarfed us by its magnificence, in a plot for which we were at best a minor footnote. Galileo marked the end of a long haul up from the first glimmering of a conscious thought in the mind of some prehistoric human ancestor a quarter of a million years ago to the triumphs of fully fledged modern science.
p.1 Not surprisingly, perhaps, we have viewed the ever-rising tide of science with an ambivalence tinged with a growing sense of alienation, of no longer being in control of our destinies.
p.1 On the other, the reaction against the hard-edged world of science found expression in a yearning for a more emotionally sensitive relationship with nature.
p.2 ...it did little to dispel Snow's point that a significant body of opinion existed within the intellectual community that was profoundly anti-science. In a curious way, this view was highlighted by Snow's observation that the word *intellectual* was, by common convention, never used to refer to scientists.
p.2 Nevertheless, there is, I believe, growing evidence to suggest that this antipathy to science has, if anything, deepened as the humanities have perceived themselves to be increasingly beleaguered by the sciences. More disturbing still is the evidence that people, particularly those of school age, are being turned off science.

A Problem in the Making

p.3 In effect, science students at these universities were nearly a whole grade class lower in ability right across the board.
p.4 We are, it seems, already witnessing the beginnings of that downward spiral.
p.5 One is a dramatic resurgence of fundamentalist attitudes and beliefs, many of which are either self-consciously anti-science or actively seek to constrain its activities in radical ways; the other is marked by the emergence of philosophies of despair among intellectual élites within the humanities.
p.5 Barry Hugill, the *Observer* newspaper's education correspondent, was recently drawn to comment that 'in the United States, the coming millenium has spawned numerous cults, supported by thousands of apparently sane people.
p.6 The second form in which this phenomenon has manifested itself is in the rise of what, in the rarified atmosphere of intellectual circles in the humanities, has come to be known as 'Postmodernism'. Postmodernism, as its name implies, owes its existence largely to the collapse of the Modernist movement that dominated the arts and literature from the end of the nineteenth century.

p.7 The resulting fragmentation of the largely forward-looking Modernist dream precipitated a pessimistic retreat into the view that there was no such thing as certain knowledge. Science itself came to be seen as one more expression of male-dominated Western cultural imperialism, a by-product of capitalism whose main function was to maintain the inequalities of the *status quo*.
p.7 In contemplating this problem, it seems to me that all these different phenomena share a common element: an information gap of potentially disastrous proportions. Neither the proverbial man-in-the-street nor many of those who avow Postmodernist views in the humanities have any real understanding of what scientists do or how science works.

What's Wrong With Science?

p.9 To be sure, there are serious moral questions to be answered about our use and abuse of science, but we need to distinguish very carefully between questions about science and questions about the exploitation of scientific knowledge. After all, it is inconceivable that *any* human intellectual activity could be so totally free of the risks of misuse that it should be accorded a privileged position.
p.9 The basis of Appleyard's argument is that science is socially and morally corrosive in th sense that it destroys the old certainties on which social life has depended for the past hundred millennia or so of human history. The sheer success of science - the overwhelming sense of power, of the ability to control the world, that it generates - has, he argues, destroyed our ancient dependence on the spiritual life.
p.11 In the chapters that follow, I try to tackle this problem head on. I explore both the nature of science and the reasons why, 350 years after Galileo, we still seem to have so much trouble coming to terms with it.

2 What is This Thing Called Science?

The Art of Science

p.12 If modern science can be said to have had its beginning with Galileo in 1632, then the philosophy of science might be said to have had its beginning with the English philosopher and man of letters Francis Bacon.
p.13 The issue at the heart of Bacon's onslaught against the medieval scholars was the certainty of knowledge.
p.13 In extolling the virtues of his new method, however, he was less than fair to his predecessors. To be sure, there had been plenty of hair-splitting to justify Bacon's outrage.
p.13 Though by no means the first empiricist among the Greek philosophers, Aristotle stood out among his contemporaries for the meticulous care with which he worked.
p.14 What lies at the heart of both Aristotle's and Bacon's approaches is the insistence on hypothesis-testing. But, in the centuries following Bacon, the 'scientific method' came to mean the 'experimental method', thanks largely to Bacon's vigorous campaign on behalf of

the developing experimental sciences. Unfortunately, this is to confuse the general with the particular. Experiments are a particular way in which hypotheses can be tested, but they are not the only way.
p.16 Science, then, is a method for finding out about the world and not a particular body of theory. Whatever else science is used for, it is explanation that remains its central aim.
p.17 I would prefer to rewrite Ryle's aphorism in terms of 'knowing *that* [X is the case]' and 'knowing *why* [it X is the case]', but the point remains the same.

Falsification, Revolutions and Programmes

p.18 Indeed, it dominated the social sciences as well as some areas of biology well into the present century where it went under the name of 'positivism' (the lable given to this approach by the French philosopher-scientist Auguste Comte, one of the founding fathers of sociology). To most lay people even now, science consists in discovering new facts about the world. It was largely this view that provided the justification for the extraordinary flowering of biological and geological collections during the Victorian period and led, towards the end of the century, to the building of the great national museums in which to house these collections.
p.19 Here, generating explanations was the key to progress, not the proliferation of descriptive generalizations.
p.19 For, as early as the middle of the eighteenth century, the great Scottish philosopher David Hume had pointed out that the induction of generalizations faces a serious problem: the only guarantee we have for the success of the inductive method is its past success.
p.19 Induction lacks the certainty of knowledge guaranteed by the deductive disciplines like logic and mathematic.
p.19 Undoubtedly the best-known attempt to solve this paradox is that of the Austrian philosopher Karl Popper. During the 1930s Popper had been particularly concerned to find some way of distinguishing between the statements of science and those of metaphysics (i.e. distinguishing statements that had some external validity from those of pure belief).
p.19 These tests, he insisted, were not attempts to *prove* a particular theory (a form of induction) but rather attempts to *disprove* it. Proof, he argued, is something that is logically unobtainable.
p.20 This led Popper to coin the term 'falsification' to describe what scientists really did. Popper's conception of science as a process of falsification dominated the philosophy of science for the better part of half a century, and still remains influential among scientists.
p.20 One difficulty for Popper's theory is the fact that much of science consists not in trying to prove theories wrong but in trying to define their limits of application by identifying the points at which the theories do not work (i.e. the areas in which they make incorrect predictions).
p.21 The second problem is that Popper's falsification procedure appears to be based on the view that causal relationships in the real world are simple 'one cause, one effect' processes.
p.22 Kuhn's conception of science appears to be in direct contradiction to Popper's and many people have viewed these two views as polar opposites. But in some ways this is to misun-

derstand the nature of their respective arguments. Popper's is a prescriptive statement of what scientists *ought* to do if they want to get things right; Kuhn's is a normative one about what they *actually* do in practice. Kuhn's description of how scientists work says nothing about whether a given theory or paradigm is correct or incorrect, merely that scientists tend to accept or reject it as a group.
p.22 But on another interpretation, Kuhn's views are quite compatible with the rationalist view that scientists adopt new paradigms only once they have tested the old one to the point of destruction and have found a better one with which to replace it.
p.23 Lakatos also made an important practical point when he observed that there is no point in rejecting a framework theory just because there is evidence against it. Without a framework theory, we cannot ask questions or design experiments. So there is no point in abandoning a framework theory unless we have a better one to replace it with.
p.25 These two views of science were characterized as the 'bucket' and 'searchlight' models of knowledge, respectively, by Popper.
p.26 If the searchlight model of science is true, them it greatly weakens the force of Hume's worries about induction. So far from being the centrepiece of science, empirical generalizations are at worst the starting-point for theory development, and at best the basis for testing a theory's predictions. This is not to say that theories in science are arbitrary.

A Chaos Theory of Science

p.27 Taken to its logical conclusion, this argument insists that even our descriptons of the world presuppose the existence of theories. In the social sciences this view underpins the claim that we are so imbued with language that the very words we use determine even the way we see the world around us.
p.28 One especially important relativist is the American philosopher Paul Feyerabend. Feyerabend's views are interesting because they are at odds with those of almost all the other leading philosophers of science.
p.29 In this sense, Feyerabend advocates what he calls 'epistemological anarchy'. His other challenge to conventional theories about the nature of science is to argue that there is no such thing as a scientific *method*. Indeed, he even wants to claim that science as we practise it has all the hallmarks of religion: it has a standard set of beliefs that its advocates must adhere to or face ostracism and excommunication.
p.29 Feyerabend, however, wants to go further: his is a plea for intellectual pluralism, and it has inevitably proved to be particularly attractive to those who want to insist that science should not be specially privileged. Indeed, Feyerbend goes so far as to claim an equivalence between science and poetry: he once suggested that we should choose our hypotheses by the pleasure they give us.
p.29 As a general recipe for how to acquire knowledge about the world, however, Feyerabend's anarchic philosophy fails to take proper notice of the fact that scientists do try to use rational criteria to choose between competing hypothese.
p.31 Science, then, is a process of intense criticism. Only a few ideas survive the first round of self-criticism on the part of the scientist who invents them and it is inevitably only these

few that we ever get to hear about.
p.32 This dialetical process is an intrinisic part of science and it serves a useful function in preventing us from becoming distracted by too many ideas at once.
p.32 The important point to emerge from all this is that science is methodological prescription rather than a particular body of theory.
p.32 In the next two chapters, I shall try to show that the methods of empirical science are in fact genuine universals characteristic of all higher forms of life.

3 A Natural History of Science

p.34 Myths, they argued, were attempts to understand and control the world.
p.34 However, from shortly after the turn of the century, a new strand of thinking began to gather momentum, which owed its inspiration to Emile Durkheim, one of the founding fathers of modern sociology. Durkheim argued that magic and religion have a rationale that is quite different from that of science. Beliefs and rituals, he insisted, are not intended to explain actions or emotions; they are not even statements about the physical world. Rather, they are simply commentaries on the nature of social life.
p.35 This claim allows for two alternative interpretations of science. One is that, while sciene obviously does work, it is not the case that all cultures practise 'science'.
p.35 The other interpretation is rather stronger. It suggests that modern science really is no different to the culturally constructed beliefs of these pre-scientific cultures: neither has any substantive validity as a description of the external world, which is, in any case, unknowable even in principle. Any successes that scence might claim to have are purely accidental. This is the view most closely associated with the cultural relativists, those who argue, following Durkheim, that seen within their own light all cultures are equally valid and equally right: there is, and can be, no absolute truth.
p.35 It seems to me that the relativists' mistake lies in assuming that because some of the aboriginals' theories about the world differ radically from ours, it necessarily follows that all their theories differ from ours.

Is Science Pan-Cultural?

p.36 Let me begin by trying to convince you that genuine science can be arrived at independently of the intellectual traditions of the modern Western world. I shall do this simply by giving three examples from different historical and cultural environments.
p.43 These three cases offer us examples where other cultures have made genuine contributions to modern science, or have come to the same conclusions that we have through careful observation.

Natural Science?

p.44 Convincing as these examples are, a sceptic might legitimately point out that they

all derive from technologically advanced cultures. What evidence is there to suggest that scientifically less advanced cultures also engage in sound empirical science?

The Science of Survival

p.55 But, as I argued in the previous chapter, science is not a body of theory: it is a method for finding out about the world that combines empirical observation with causal inference.
p.56 Within the technological constraints of their economies, all the peoples I have discussed are clearly engaged in very sound empirical science. To be sure, most of it is cookbook science, based on the recognition of regularities in the phenomenal world.
p.57 The fact that the solutions had to be seen to be workable meant that mathematicians' ideas were under an intense form of (non-genetic!) Darwinian selection.
p.57 I shall return to this issure in Chapter 5 because it raises the question of why we seem to think naturally in this way.

4 The Roots of Science

p.58 I have argued that empirical science is a genuine human universal. In this chapter, I shall broaden this claim even further by arguing that the scientific method is not merely typical of all humans, but is also a key feature in the lives of most birds and mammals.
p.58 It seems to me that two processes underpin any organism's ability to learn about the world: these are classification and causal inference. The first provides the generalizations that allow us to note regularities in the world, while the second allows us to make sense of these regularities by organizing them into coherent logical sequences.

Nature's Own Scientists

p.59 One exaple of the type of concept being taught is th concept *tree* (or *tree-ness*). During the training sessions, the pigeon would be shown hundreds of different examples of the concept: these might include particular trees of different species, aerial views of forests, forests in close-up, branches of trees, woods in winter, woods in summer and so on.
p.61 When discrete categories are imposed on a continuum, the boundaries will inevitably be somewhat arbitrary.
p.62 A more significant example of monkeys' abilities to categorize the world is povided by a series of experiments carried out by Verena Dasser.
p.63 Is there any evidence to suggest that animals also use a cause-effect approach as the basis for describing the relationship between two events in the world as they experience it?
p.64 In contrast, a control group who were trained on the first stage (light plus food) but not the second stage continued to approach the hopper at the same rate as they did before. It seems that rats, at least, store knowledge about the world in the form of simple causal hypotheses.
p.65 It is important to notice in this context that the causal hypotheses that the rats appear

to be using need only take the form of simple correlations: 'Y follows X.' They need not have any *explanation* (or theory) in mind as to *why* X is always followed by Y. In this respect, the rats conform to the classic definition of causation given by David Hume, the eighteenth-century Scots philosopher.

Children as Natural Scientists

p.69 Hypothesis-testing is also very much in evidence in the way children learn word endings (for example, the correct form of the past tenses of English verbs).
p.69 Other aspects of the way children learn languages are reminiscent of some of the rat experiments I described earlier.
p.70 Using a format in which young infants are shown short filmed sequences, he found that children as young infants are shown short filmed sequences, he found that children as young as four-and-a-half months are more sensitive to film clips showing 'natural' causal relationships between objects (e.g. a green brick moving immediately after being struck by a red brick) than to 'unnatural' relationships (e.g. the green brick moving after the red brick came to a halt 6 cm short of it, or a half-second after being struck by the red brick).
p.70 Leslie argues that these results undermine Hume's assertion that our perceptions of causality are based on generalizations from the repeated experience of the co-occurence of two objects or events.
p.71 In other words, children begin to interpret events in the world in causal terms long before they can possibly have been influenced by the cultural preconceptions of the society into which they happen to have been born.
p.71 Leslie has taken this argument even further by suggesting that this causal sense is a crucial component in the child's development: it provides a kind of scaffolding that automatically gives the world sufficient coherence for the child to begin to make sense of its real complexities.

Learning Rules of Thumb

p.72 Even more interesting, perhaps, is a claim made by the Boran honey-gatherers that the birds will attempt to deceive them by deliberately underestimating the distance to the bees' nest when it is more than about 2 km (approximately the limit to which Boran are prepared to go in search of a nest because of the length of time for which their herds will be left unguarded).
p.73 Another example of natural science concerns the use of medicinal plants by chimpanzees.
p.74 Chimpanzees are not the only species to have noted the correlation between health and particular foods.
p.74 My last example, once again, concerns rats. Animals' abilities to make inferences about the world in which they live depends, in the final analysis, on their ability to acquire information about the regularities in the world's behaviour and, from these, to infer geeral rules of thumb that allow them to predict with tolerable accuracy what is likely to happen in the future. A particularly enlightening set of experiments on just this point has been carried

out by Tony Dickinson and his colleagues.
p.75 Dickinson argues that the only plausible interpretation of these results is that when the rats encounter a new problem, they have to think about it; but once they have leaned what the correct response is, the rule is transferred into a habit that they don't have to think about.
p.75 The essence of my argument has been that empirical science is something intrinsic to life itself for these organisms.

5 Why is Science so Successful?

p.77 All this begs the question as to why the scientific method should be so widely adopted. What is it about the empirical approach that makes it the preferred solution?

Pragmatic Realism

p.79 Scientists do use a falsifiabilitiy criterion as recommended by Popper, but they use it as a criterion for identifying useful hypotheses not as a prescription for how to do science. Far more important to a scientist is another much less familiar concept of Popper's, namely the notion of a 'fair test'.
p.79 In science, the phrase 'All other things being equal...' is probably the single most important component of any experimental test.
p.79 The business of hypothesis-testing is neither easy nor straightforward. Nature is no respecter of persons when it comes to ill-conceived theories, and it is all too easy to fall into the GIGO ('garbage-in/garbage-out') mode of science if you don't think long and hard about exactly what you are doing and precisely how your pet theory works.
p.80 What, then, defines a good theory? In his book *The Rationality of Science*, the philosopher William Newton-Smith lists eight key features. These are: (i) observational nesting (the theory's ability to explain the successes of its predecessors); (ii) fertility (its ability to generate new ideas to guide future research); (iii) track record (its achievements in making correct predictions in the past); (iv) inter-theory support (its ability to provide additional evidence in favour of another theory); (v) smoothness (the fact that it needs few auxiliary hypotheses to explain its failures); (vi) internal consistency (that it contains few statements that lead to the acceptance of logically imcompatible predictions); (vii) metaphysical compatibility (that it meshes well with our other beliefs, including our general metaphysical position); and (viii) simplicity (a version of Occam's Razor which says that, when all other things are equal, simpler theories are to be preferred, if only because they will be easier to compute). The basis of his argument is that, if we apply these criteria carefully, the growth of knowledge will proceed in a genuinely rational way.
p.80 Newton-Smith is specifically concerned to counter the anti-rationalist views advocated by Kuhn and Feyerabend...
p.82 Our real concern lies in trying to understand the world well enough to survive in it: we have to be able to plan for tomorrow.

p.82 The philosopher Nicholas Maxwell wants to go further by insisting that there are even stronger grounds for justifying modern scientific practice. He argues that fundamental assumption underlying science is that the world is comprehensible, that it has a certain internal consistency.
p.83 The only possible recourse open to a relativist at this point is to argue that the success of a theory does not guarantee its truth, merely that it happens to predict the results we observe. But now we are in danger of collapsing into solipsism (the philosophical view that only my mind exists, and the rest of the world is simply a figment of my imagination).

Mental Models

p.83 We can, I think, go one step further in justifying the pragmatic arguments for the validity of science. In Chapter 4, I argued that animals use essentially the same kind of causal logic that we do. Underlying this conclusion is another important idea, namely the fact that rats appear to code their knowledge about the world in the form of hypotheses. In effect, they construct models about how they think the world actually is, and use these models to predict the future.
p.83 The importance of this observation lies in the fact that not only is this a close parallel to what scientists do, but it is also a close parallel to the way psychologists are now beginning to think that people store knowledge about their experiences. This so-called 'mental models' hypothesis owes much to the work of psychologist Philip Johnson-Laird.
p.84 Johnson-Laird's claim is that storing knowledge in the form of causal hypotheses (or models) is extremely efficient for two reasons. One is that it is doubtful whether even humans have sufficient memory capacity to learn the right response to a stimulus by induction alone.

Does Scientific Programme Really Work?

p.86 ...the relativist faces a serious challenge because his position now depends on being able to show that science is no more successful than any other belief system such as magic. In effect, this entails showing that science is successful only as often as we might expect if we selected our theories about the world at random.

Modular Science

p.88 Given that science has been so successful, we have to ask why: what is it about the methods of science that has made it possible to achieve such spectacular successes?
p.88 One such featuyre is 'modularization' whereby complex phenomena are partitioned into smaller segments that are then dealt with piecemeal. This is the feature that many outside science castigate as reductionism, but which scientists have always insisted is the great strength of their approach.
p.88 Part of the problem here is that reductionism can refer to two quite different things: one is theory reduction in the philosophical sense (sometimes referred to as 'nothing but-ism') and the other is methodological reductionism (which is a heuristic device or prescription for

how to study the world).
p.89 However, this is something very different from methodological reductionism. The essence of the argument here is that nature is far too complex to study as a single entity. The only way to make any progress is to divide it up into more manageable chunks and get to grips with these one by one.
p.90 But holism can also mean something more than this. It is not so much that the world is too complex to be explained by simple disciplines like chemistry, but that there are important components to it that are not physical in the conventional sense and so cannot be studied by science. 'There is more to life than biology' might be an appropriate slogan. The great problem with this view is that it invariably leads us straight into mysticism and religion: belief in supernatural forces often lurks in the background in this version of holism.
p.90 But perhaps the greatest objection is that holism is simply a very pessimistic philosophy.
p.90 One other point is worth noting about holism. It seems that people are much less worried about attempts to reduce chemistry to physics than they are about attempts to reduce human behaviour to biology. It is a view that is particularly prevalent in the social sciences, and it owes its origin to Durkheim's claim that human behaviour can only be explained in terms of human behaviour.
p.94 On the other hand, of course, there are legitimate questions you *can* answer from the other side of the road without having to lift the bonnet.
p.95 Reductionism in the sense of theory reduction can tell us about the mechanisms that underpin the phenomena we experience. But it cannot answer other important questions about function, ontogeny or evolutionary history. These, as all good biologists know, have to be dealt with separately using more appropriate (albeit equally 'reductionist') methodologies.

6 Unnatural Science

p.96 We have to be careful not to confuse the message with the messenger here: Wolpert's argument is largely concerned with the *findings* of science, whereas my emphasis has been on the *methods* of science. My point has been that these methods are, at root, simply the natural mechanisms of everyday survival.

A Philosophy of 'As If'

p.98 In effect, scientists operate on a principle of 'As if' - 'Let's proceed *as if* theory X were trye (even if we know that it really is not).' If you like, Newtonian physics is simply an emergent property of quantum physics: it's what happens when you scale up and average out all the tiny quantum effects at the sub-microscopic level. The bottom line is that we understand why it turns out to be a reasonable approximation.
p.99 (...I suspect that social anthropologists have been impressed by the variety found in human cultures only because they are blissfully unaware of the range of variation found in the rest of nature.) A mathematical model is not an attempt to provide a complete description

of a natural phenomenon; rather, it is an attempt to see how far we can get with a limited set of principles, an attempt to establish the model's boundary conditions.

The Logical Mind

p.109 That we find it difficult to think logically has been demonstrated repeatedly by psychologists.
p.110 The American psychologists Amos Tversky and Daniel Kahneman found that people often have surprising difficulty interpreting probabilities.
p.113 Science's success hinges on a very rigorous application of the principles of logical deduction and the meticulous testing of hypotheses.
p.113 But there is another factor that seems to be important in the context of the more conventional sciences, and this is the fact that our minds seem to be predisposed to deal with social matters rather than the nature of the physical world.

7 The Social Brain

p.114 We humans seem to have a particular fascination for the complexities of the social world. By comparison, our interest in the physical world that surrounds us seems to be desultory, at best.
p.114 I suggest in Chapter 4 that children behave as natural scientists, formulating and testing hypotheses about how the world works. But recall that the focus of their attention is, in fact, on animate objects.

A Window on Our Minds

p.116 However, when the task is presented as a purely social problem, most people get it right.
p.116 Cosmides and her colleague John Tooby have argued that the human mind is specially adapted for detecting social cheats - that is, people who do not fulfil their social obligations or abide by the rules that society has evolved to enable it to function smoothly.
p.116 It's what Garrett Hardin termed the 'tragedy of the commons': the fact that it invariably pays everyone in the short term to cheat just a little on the system even though in the long term they would all do better to cooperate with each other by adhering to society's rules.
p.116 Cosmides and Tooby's arguments builds on earlier work by the evolutionary biologist Robert Trivers who suggested in 1971 that what he termed 'reciprocal altruism' was an evolutionarily viable strategy in a Darwinian world.
p.117 In such context, the best strategy turns out to be a very simple one. In the technical literature of evolutionary biology it's called 'Tit-for-Tat' (or TFT for short).
p.117 The problem for TFT is that it depends on your repeatedly playing against the same individual. In a one-off game, cheating always pays.

p.117 Humans live in a particular social world: the social world has, if you like, been our primary evolutionary adaption, our way of solving the Darwinian problems of survival and successful reproduction.
p.118 All human societies use smear campaigns and snide remarks to enforce the social graces. And we are ever-watchful to see that the rules are being adhered to (at least by everyone else, even if not always by ourselves).

How Monkeys See the World

p.118 The claim that the human mind is especially adapted to handling social problems was spun off another more general principle known as the Machiavellian Intelligence hypothesis.
p.118 ...the hypothesis was formally proposed in the late 1980s by two British psychologists, Dick Byrne and Andrew Whiten, as an explanation for the fact that monkeys and apes (the primates) have much larger brains (relative to their body size) than any other group of animals.
p.118 The Machiavellian Intelligence hypothesis attributed primates' larger-than-average brains to the fact that they live in much more complex social groups than all other animals.
p.120 Primates need big brains, so the Machiavellian Intelligence hypothesis argues, because their social world is much more complex than the physical world. Whereas rules of thumb in the physical world remain more or less constant throughout an animal's lifetime (predators are always dangerous, rain is usally followed by a burst of fresh growth in the vegetation, flowers presage fruits a month or two later), the constancies in the social world occur only at the very highest level.
p.121 Monkeys, as we saw in Chapter 4, are especially good at learning social categories: they can distinguish between individuals and their dominance ranks, and recognize relationships like 'is friends with'.
p.122 The social life of monkeys and apes appears to be unique in one other important respect, and this is the extent to which they use tactical deception in their relationships with each other.
p.124 If you spend time watching the social groups of monkeys and apes, as many of my colleagus and I have done in both the wild and captivity, the one thing that strikes you most is the extraordinarily complex social balancing act - a real-life soap opera - that is being played out among the animals.
p.125 Primates spend much of their time monitoring very carefully what is happening around them.
p.127 The relationship between neocortex size and group size suggests that primates had to evolve increasingly large neocortices in order to cope with the increasingly demanding task of keeping track of the larger number of social relationships that occur in larger groups.

The Mind's 'I'

p.128 One last component in this story concerns the psychological processes involved. In order to engage in the kinds of sophisticated social strategems that monkeys, apes and hu-

mans seem to specialize in, we need to be able to stand back from our immediate selves and ask how another individual is likely to repond when we behave in a certain way.
p.129 That the ability to think reflexively is essential for a competent social life is clear from studies of humans who suffer from the condition known as autism.
p.129 Autistic children appear to lack another important psychological attribute, and this is teh ability to engage in imaginary or make-believe play.
p.129 Leslie has argued that the ability to engage in pretend play and that of being able to lie are closely related, appearing at about the same time during normal child development. They are, he believes, a reflection of the child's growing ability to detach itself from its personal perspective on the world so as to see the world from someone else's point of view.
p.130 The important point is that children under about the age of four years are unable to distinguish other people's beliefs from their own; they cannot recognize that someone else can hold a belief about the world they know to be false. But from about four-and-a-half years onwards they can. Psychologists now refer to this as acquiring a 'theory of mind' (or ToM for short): by this they mean that a child starts to form theories (or, if you prefer, hypotheses or beliefs) about other people's states of mind.
p.130 However, it seems that all human beings who develop normally develop a theory of mind, and this is independent of cultural background.
p.131 It seems that they too have the capacity for ToM. But when she gave the same test to monkeys, they failed it: monkeys, it seems, cannot attribute false beliefs.
p.131 So although monkeys impress us by the complexity of their social strategems, they achieve these by using rather less sophisticated psychological processes than we (and perhaps chimpanzees) do.
p.132 Only humans, it seems, can detach themselves sufficiently from their own view of the world to produce, on the one hand, fictional literature and, on the other hand, science and religion.
p.132 Young children, autistics, monkeys, other mammals, birds and fishes can learn generalizations about the world, but fail to take that one crucial step of going beyond the generalization to seek the reasons why they take the form they do.
p.133 But not everyone is a Shakespeare or an Einstein. The great products of human culture are not the collective efforts of the five billion people who are currently alive. They are the products of a handful of particular individuals in whom the unique skills to which all humans are heir have been honed to a special sharpness. And herein, perhaps, lies the rub. To appreciate great science and literature probably requires the learning of skills that we do not naturally possess.
p.133 We can play a single instrument's part and very quickly show a novice how the composer built up a musical sound. But none of us can begin to imagine what a sixteen-dimensional universe is like, or what infinity really means. At this point even the professional scientists abandon the attempt and confine their attention to the mathematics. The problems that this creates for popular science writing are the subject of the next chapter.

8 Science Through the Looking-glass

p.134 My theme so far has been that although the processes or methods of science are very much the stuff of everyday life, the theories that this methodology has produced are often very different from what common-sense experience might lead us to believe is the case. This ultimately gives rise to a serious problem about how we popularize science.

A Problem in the Public Domain

p.135 When Charles Darwin published his *Origin of Species* in 1859, he produced one of the classics of English literature. Written in elegant prose, its arguments lucidly laid out, the book was not only read by his zoological colleagues, but was also widely appreciated both by academics from other disciplines and by the public at large.
p.135 But this was far from true of physics by Darwin's day. Yet it once had been. Aristotle's works, for example, could be read and appreciated by anyone with a reasonable level of education.
p.135 But when Newton's *Principia Mathematica* rolled off the presses a mere fifty-five years later, things suddenly took a very different turn. At a stroke, science passed through the looking-glass and became incomprehensible to all but the professionals.
p.135 What had happened was that mathematics had become an essential component of sciences. The arguments were raised on to a new plane whose understanding was only possible if the reader was familiar with the new mathematical techniques that included calculus and the beginnings of probability theory. Physics became opaque to the non-specialist.

A Metaphorical Problem

p.142 The answer is neither of these. What unites physics and evolutionary biology (and, incidentally, computer science) is that they deal with phenomena that everyday experience does not equip us to talk about.
p.144 ...in the sciences the important thing was what you had to say, not how you say it, whereas in the humanities what you said (if anything at all) was irrelevant, but how you said it appeared to be everything.
p.145 Schwartz points out that many people find abstract languages of this kind appealing precisely because it has a distinctly poetic quality. It has an intrinsic beauty of its own. Dressing simple ideas up in obscure language makes them seem more profound than they really are. Moreover, like all good poetry, it can be read as saying almost anything you like: it can mean all things to all people.
p.146 The sentences produced by the program are, of course, meaningless nonsense, but the human reader can extract quite meaningful interpretations from them! The success of the experiment can be gauged by the fact that the book even received quite approbatory reviews in leading newspapers.

Science and Society

p.147 When science does feature in these papers, it tends to be in the geewhizz vein. It

rarely involves any background analysis of the kind that even the most trivial political event would invite, and it seldom tries to place the discoveries being reported into their context within the relevant discipline. This is, I think, largely a consequence of two failings in the media.

The Philistine in the Laboratory

p.153 Far too many of those who consider themselves to be artistically well-informed are scientifically illiterate. But if never having listened to a Bach cantata or seen an Australian Aboriginal rock painting is an astonishing cultural lacuna in one's life, then so is not being interested in how stars are formed or how genes produce bodies in that greatest of all miracles on which life itself so precariously depends. Science is, by any standards, one of the most astounding achievements to date of the human mind: how is it possible for some people to be so woefully ignorant of so great a part of our cultural heritage?

9 The Open Society Revisited

p.154 In this chapter, I shall be asking the converse question: what happens when science does not have such a free hand, but is constrained in what it can do by social or political interests?
p.154 Attempts to impose intellectual frameworks that are wholly derived from the local culture are bound to interfere with the natural processes of science. If the theoretical structure is preconceived and wholly impervious to change, then progress cannot occur because the theories remain inviolate to criticism. Paradoxically, then, in suggesting that science is socially constructed, the relativists have in fact identified the very thing that makes productive science impossible.

Through a Glass Darkly

p.155 'Science,' wrote Wolf Lepenies, a leading German social theorist, 'must no longer give the impression it represents a faithful reflection of reality. What it is, rather, is a cultural sysytem, and it exhibits to us an alienated interest-determined image of reality specific to a definite time and place' (Lepenies, p.64).
p.156 The typical approach that the cultural constructionists adopt is to take a particular scientist (such as the biologist Charles Darwin or the chemist Robert Boyle) and try to show that his conception of the problem(s) he became interested inwas largely a product of the society in which he happened to live.
p.156 Most scientists, faced with this kind of analysis, are inclined to exasperation. Where else, they will ask, are you to get your hypotheses from? They can only come from the experiences of the individual scientist or from the existing theoretical structures of the discipline, and either way they reflect the scientist's cultural milieu (in the one case social, in the other case scientific). Bu this does *not* mean that they stop there, for that would be to

imply that scientists do not actually follow their own methodological prescription of testing the hypotheses that they have proposed.
p.157 To be sure, the analysis *is* historical in the sense that it seeks to place the scientist or the particular problem under investigation into its historical and cultural context. But there history ends. Any sense of th temporal *process* of history, that history is, quite literally, a dynamic story that runs and runs, seems to be totally missing. The sociologists' conception of history is a purely static and contextual one: it is not historical at all.
p.157 The proverbial man-in-the-street is, of course, now reasonably familiar with the notion of genes and the process of evolution. Yet the layman's grasp of the details of evolutionary theory is invariably lamentable. Notions that were eradicated from biology half a century or more ago ('evolution for the good of the species', 'nature red in tooth and claw', 'survival of the fittest [i.e. the strongest]' to name but three) pepper the discussion because they are still widely believed by the lay public (and even by the non-biological disciplines within the sciences) to be substantive components of evolutionary theory...
p.157 More often than not, the relationship between science and popular culture is the reverse: modern cultue has acquired many of its ideas secondhand from science, often in emasculated form.
p.157 In many of these cases, the sociologists' problems seem to be due to their complete lack of familiarity with the technical content of the scientific disciplines they have been trying to study.
p.158 Our present understanding of primate societies and their evolution owes little to studies of chimpanzees, and even less to the work of Jane Goodall herself, despite the genuinely important and very substantial contributions that she and many others like her have made to our store of knowledge about the behaviour of monkeys and apes. And it owes nothing at all to the feature stories that appeared in the pages of the *National Geographic* magazine.
p.159 It would, of course, be churlish to condemn all sociologists of knowledge: even the sociology of knowledge is not without its heroes.
p.159 Lynch is, of course, simply emphasizing what every good anthropologist knows to be true: participant observation (immersing oneself in an alien culture in order to understand it from the inside) is the only possible way to proceed. And there is no question but that science *is* a foregn culture, as much for the sociologist as for the layman. For Lynch, the sociologist's programme has been at best hypocritical: it has done little more, he argues, than foist its own simple-minded preconceptions on to the fabric of science. Bravo for common sense!
p.160 Robin Horton has been another lone voice crying in the wilderness - in this case, the wilderness of contemporary social anthropology. He has vigorously defended the view that traditional religious systems function as a primitive form of science in pre-modern societies. 'One of the principal intellectual functions of traditional African religions,' he writes, 'is that of placing everyday events in a wider causal context than commonsense provides' (Horton, p.56).
p.160 Horton contrasts the way religion functions in traditional societies with the way it does in modern post-industrial European societies: in our modern societies, science has tended to replace the explanatory framework function of religion, leaving it only the moral and psycho-

emotional spheres to deal with. One consequence of this is that it is possible for people to be both scientists and religious. In this respect, he argues, it is religion in our societies that is odd; in traditional societies, religion permeates everything a person does, the way he thinks about the world as well as his behaviour towards others.
p.161 Before bringing this section to an end, let me be quite clear about what I am saying. I am not claiming that scientists' ideas are never influenced by the common culture of the day; nor am I saying that they never impose their political or other preconceptions on the world they study. Of course they do, and probably much more often than we would wish. Mistakes of logic are made, the evidence fudged and the results of tests fiddled, all in a desperate effort to preserve a theory that an individual has committed most of his or her life to. Who amongst us wants to end a lifetime that has been devoted to the pursuit of a theory with nothing but failure to show for it? Scientists are human, and fall prey to all the foibles to which humans are prone.
p.161 But this is not the end of the story. Two things help to prevent malpractice on a massive scale becoming universal among scientists. One is the inherent scepticism of colleagues who would prefer to see their own alternative theories triumph. For better of for worse, it is precisely the competitive individualism of science that has saved it from the cultforming fate of most religious and political sects. At the same time, however, rampant individualism remains less conspicuous in science than it does in most aspeacts of everyday life because scientists form a community with a common purpose. That sense of communality leads to much sharing of information and ideas, even with complete strangers. The second factor that preserves the integrity of science is the uncompromising intransigence of nature: you cannot force nature to behave in accordance with your pet theory, no matter how hard you try.

The Purse-Strings of Science

p.161 A more serious claim, perhaps, is the suggestion that sicence is in the pocket of its paymasters, that its continued funding depends on its willingness to reinforce the economic and political *status quo*. It is easy to point to well-known examples that seem to back up this claim.
p.164 So far from driving the progress of science by demand, the reality is that the burgeoning empires have, more often than not, merely provided sufficient surplus capital to enable science to be funded without raising too many public objections. After all, it took two world wars to persuade most governments that investment in basic science was a worthwhile use of taxpayers' money.
p.164 But he himself regarded all these ingenious machines as of such trivial interest that he left no written accounts of them, despite the fact that he scribbled voluminously, producing ten mathematical treatises on geometry and physics that have survived and at least another six lost works that we know about from references in other sources. The things he considered sufficiently interesting to write down concerned such esoteric questions as how to calculate mathematical functions or why bodies float.
p.165 But is was his esoteric mathematical work rather than his engineering devices that

were to stand the test of time, for they laid the foundations on which Newtonian physics was later to be based.
p.165 ...not to mention the Americas, where French gunpowder found its way to the revolutionary armies of the nascent United States and materially contributed to the defeat of their British colonial masters in the War of Independence.
p.166 But the French government had not asked Lavoisier to produce a theory of chemistry. Had his gunpwder not been of such extraordinary quality, there would surely have been words in high places. Not only did the government have no interest in a new theory of chemistry, it did not even need one to produce high-quality gunpowder: that was simply a matter of getting the mixture right, something that Lavoisier had already managed to do by simple cookbook trial and error. The theory of chemistry emerged as a by-product of Lavoisier's practical work, aided and abetted by a bit of curiosity. The French government's part in the whole business was limited to providing Lavoisier with a salary plus some space down at the Arsenal to set up a laboratory.
p.166 No amount of throwing money at the wall will, of itself, solve problems at the frontiers of science. Answers can be developed to the more immediate problems of technology in this way, but science needs time and motivation. Scientists will take up the challenge only if they themselves have an intrinsic interest in the problems concerned. It's all a question of psychology. Scientific research is too frustrating and boring most of the time to sustain the interest of anyone who is not fired by an overriding fascination for a particular problem.

The Subversion of Science

p.167 This much is clear from the fact that when public interest does attempt to direct science, the science it produces is rarely especially successful. I will offer just two example that illustrate different aspects of the problem.
p.168 The great irony, indeed tragedy, of this story is that at the time of Lysenko's rise to power, the Russian geneticists working under the leadership of Sergei Chetverikov were well ahead of most of their European and American rivals. During the 1920s Chetverikov had been able to demonstrate that a species harbours a vast reservoir of concealed genetic information in the form of recessive alleles. It was the rediscovery in the 1930s and 1940s of much of Chetverikov's work by geneticists of the calibre of R. A. Fisher, J. B. S. Haldane and Sewall Wright that proved to be instrumental in overthrowing the then accepted view that evolution was a consequence of the frequency of genetic mutation, so paving the way for the synthesis of the Darwinian and Mendelian theories into the modern theory of Neo-Darwinism.
p.169 A less well-known example is the effect that Islamic religious fundamentalism had on the rise of Arabic science during the thirteenth and fourteenth centuries. Islam's insistence that everything of any consequence had already been written down in the Koran made it impossible for the philosopher-scientists of the Arab world to debate openly any of the newly discovered dimensions to science.
p.169 The result, as Toby Huff has pointed out in his book *The Rise of Early Modern Science*, was the active suppression of the developing sciences in the late medieval Islamic empires of

the Near East and North Africa just at the point where they were leading the world in the embryonic sciences of chemistry, astronomy and physics.
p.169 Al-Rashid's death in 1197 marked the beginning of the end for Arabic liberal science in the West.
p.169 Fundamentalisms of any kind, whether religious or political, are a serious hazard for science. Indeed, any attempt to redefine the nature or concerns of science places the growth of knowledge at risk. In recent years a number of attempts to constrain the free range of science have emerged out of the self-styled radical philosophies developed by some feminists and, more recently still, by the politically correct movement.
p.170 A second possibility is that the two sexes genuinely differ in their emotional responses, such that men make better scientists than women because they are able to achieve a greater degree of objectivity towards their subject-matter. But to condemn science because it might reveal that sex differences are built into the human psyche is a bit like smashing the microscope that reveals the bacteria that cause illness.
p.170 Like all attempts to constrain science within a particular political or religious framework, these 'radical' critiques of science are unlikely to help us deal with the practical problems of day-to-day survival.

The Hidden Persuaders

p.171 If State control is bad for science, the lack of public understanding has to be worse. We humans are just too susceptible to the herd instinct. Religions are so much a part of our lives that we commonly fail to recognize how easily we fall prey to the will of small influential groups. But the results are to be seen all around us in the fanaticism and militancy generated through the ages in the name of religion.
p.171 The dangers inherent in these kinds of movement lie not so much in their particular beliefs, but in their demands that adherents surrender their independence of mind. Buddhism, with its emphasis on self-help and personal achievement, remains the one shining exception to what is otherwise a near-universal rule. Once we humans are reduced to being mere believers, we seem to be incapable of making balanced judgements. The stranglehold that organized religions have had over the human mind through the centuries have given rise to such extraordinary incidents as the 'Witches of Salem' in the USA and the 'Devils of Loudun' in France during the seventeenth-century Islam.
p.172 He emphasized the nature of the world as an organism (something not too remote from the Gaia hypothesis being advocated today).
p.172 The Romantic movement's artistic contributions to the sum of human culture were, of course, enormous, especilaly in music. Its origins and psychological background are, however, deeply suspect. It smacks of a dubious anthropocentrism, an attempt to place humans at the centre of the universe merely because we experience that universe through our senses. It is redolent with a hankering after a purpose for life in a universe that contemporary astronomy and biology were inexorably demonstrating to be both accidental in origin and purposeless in existence. It was a conscious attempt to try and rectify what its supporters regarded as the awful wrong done to the human condition when Galileo unceremoniously displaced us

from the centre of the cosmic stage. It was a desperate cry for help from a bewildered and frightened child who had just discovered that it was alone in a room that it had assumed was peopled with adults.
p.173 Moreover, there can be little doubt that the anti-scientific and anti-liberal views fostered by the Romantics contributed significantly to an intellectual climate that allowed Nazism to flourish unchallenged.
p.174 The difference, perhaps, is that science is less narcissistic than art, preferring to marvel at the wonders of the external universe rather than becoming mesmerized by the fantasies of the human mind.
p.174 We can marvel simultaneously at both the physical mechanism and the effect it has on our taste buds without having to feel that there is any conflict between these two experiences. The one does not diminish the other.
p.174 I can do no better than to end this chapter by quoting the philosopher Dan Dennett's reflections on the way modern neurobiology has debunked pseudo-religious mystical views of human consciousness: $\cdots$ The 'magic' of earlier visions was, for the most part, a cover-up for frank failures of imagination, a boring dodge enshrined in the concept of a deus ex machina. $\cdots$ When we understand consciousness - when there is no more mystery - consciousness will be different, beauty, and more room than ever for awe. (Dennett, p.25)

10 Divided Loyalties

p.176 I have argued that much of the negative reaction towards science arises from a failure to understand just what it is that science is all about. Yet we are now all dependent on science to sustain our day-to-day lives. Neither we in the industrialized nations nor those in the developing world could return to pre-industrial agricultural economies without incurring terrible consequences in social and demographic terms.
p.177 ...the human mind was not designed as a rational scientific mind. In a very real sense, we have to work against our natural instincts. There are no easy answers to offer at this time, but we must, and should, give the problem serious consideration before it is too late.

Two Cultures

p.177 What we are witnessing now would simply be the last lingering doubts in the aftershock of Galileo's first astonished glimpse of the moon's surface through a telescope nearly four centuries ago. But the problem may not be so simple. It may have much more to do wth the nature of being human. Emotion is so deep a part of our psychological make-up that it cannot be so easily rooted out.
p.177 Or can we instil these skills in everyone, albeit by dint of long periods of training? On a more worrying note, is the rationality of science powerful enough to overcome the deep psychological need for faith and belief that so characterizes our species? If it is not, the advance of science may be creating a two-class polity in which there are those who are intellectually capable of learning about science and those who are not.

p.178 Paradoxically, Postmodernism can be seen as a welcome advance in the direction of science on the part of the humanities, at least in the sense that it represents a realization of one of the processes fundamental to the scientific method, namely the challenging of existing assumptions and the generation of alternative hypotheses. Where Postmodernism fails its practitioners, however, is in its deliberate refusal to implement that other important cornerstone of science, the testing of hypotheses.
p.178 It simply isn't good enough to present a series of alternative viewpoints without making any attempt to choose between them. There *are* standards of scholarship, and any proposition about the real world must be right or wrong.
p.179 Science is not 'just another' vague theory, as some of the sociologists of knowledge would have us believe. The theories of science actually work (at least given time and patience!), and they work because the methods of science come as close as is possible in this imperfect world to guaranteeing success.
p.179 The optimistic view is that these aberrations are a consequence of ignorance. It suggests that the apparent gulf between the sciences and the humanities may be just an attitude of mind; and, given that solutions to attitudes of mind are usually just matters of education, there is every reason to hope that progress can be made. But we cannot leave such things to fend for themselves. Science is a precarious edifice: it needs only a moment of neglect for it to crumble away to dust.
p.180 There, the Creationist lobby, with its fundamentalist religious beliefs, is a significant force that has been threatening to derail the entire process of scientific education for some time. To this has been added in recent years the contemporary versions of the Inquisition fostered by the 'politically correct' fringes of the humanities.

Whatever Happened to Renaissance Man?

p.180 In the meantime, however, we urgently need more extensive popularization of science as well as a better quality of science journalism. Popular accounts of science must move away from the magical 'hero-quest' and 'gee-whiz' varieties to a more realistic attitude in which science is reported as it really is.
p.181 We are caught in a cleft stick here. Can we instil the basic tools that children need to do science at an early painless stage, just as we teach them to read?Or is science more like learning to play a musical instrument - hours of enforced agony that only begin to pay their dividends of pleasure years later, and then only for the gifted few?
p.181 But I do agree wth him that the root of the problem lies in the fact that science teachers themselves are not trained in the right way.
p.183 This being so, we should consider focusing school science on what has dismissively been termed the 'soft' sciences, namely animal behaviour, ecology and psychology. These are areas of science that are intuitively easier to understand because we can relate to their subject-matter more easily.
p.184 Governments of all persuasions will certainly baulk at the cost, but I am not sure we really have much choice in the long term.
p.185 Yet entertaining as these places are, they focus predominantly on the 'gee-whiz' aspects

of science. They function at best simply to stimulate people to find out more. Ultimately everything will hinge on training good-quality science teachers who can inspire young people to go beyond the surface glitz to the exciting world of ideas.
p.185 One thing is certain: if we want to survive the next century or so, we need to change radically the way we teach science. Such changes will take time to implement, and their impact on the public domain will take even longer...

A Salutary Lesson

p.186 Their farms prospered and their cattle herds grew. At its peak the colony amounted to some 3000 souls scattered in 280 farmsteads around the southwestern coast. By the twelfth century they even had their own bishop and their own parliament.
p.186 But as temperatures in the northern hemisphere began to decline with the onset of the Little Ice Age of the mid-fourteenth century, things began to go dreadfully wrong.