[[Note: Figure captions are at the far end]]

Lucidity and science
III: Hypercredulity, quantum mechanics, and scientific truth

Michael E. McIntyre

Centre for Atmospheric Science at the Department of Applied Mathematics and Theoretical Physics, Silver St, Cambridge CB3 9EW, UK.

Version of 27 April 1999, with minor additions, amendments, and updates after publication in *Interdisc. Sci. Revs.*, **23**, 29–70 (March 1998). See especially Ref. 302 and the further comments on Goodhart's law. On sea-level rise, see the *Corrigendum* to Notes 258 and 295, reproduced at the end of this file as Note 400. It has appeared (slightly corrupted) in the December 1998 issue of *Interdisc. Sci. Revs.* and is also posted in my web pages, `http://www.atmos-dynamics.damtp.cam.ac.uk/people/mem/` See also the updated Note 281.

Scientific research can reasonably be described as a search for truth, in an important and nontrivial sense. But respect for the scientific ideal is incompatible with the myth, or instinctive, quasi-religious belief, that science is about discovering final, infallible, absolute or ultimate truth. That myth, if publicly endorsed by scientists, inadvertently or otherwise, is perilous because it fuels tribal conflicts like the current 'science wars' and increases public confusion about science. This in turn helps the psychological, social, and economic forces, including the forces within big commerce, that work toward discrediting the scientific ideal and ethic for reasons both conscious and unconscious, restricting our options for coping with an uncertain and dangerous future. Future possibilities include the risk of substantial sea level rise, continuing unstoppably for a century or more after first detection. Also possible — and arguably likely if the scientific ideal is too far discredited — is the destruction of the system of free market democracy and free trade, the government by consent and prosperity of individuals on which big commerce itself depends.

Our understanding of the actual and potential human behaviour patterns that might lead to such destruction is being sharpened by evidence from linguistics, palaeoclimatology, palaeoanatomy, and genetics, and from research on perception and cognition. It is remarkable that any such self-understanding is possible for us, and even more remarkable that any human society allows such matters to be openly discussed. Both things demonstrate our species' adaptability and the power of cultural evolution — more precisely the adaptive power of the intimate and intricate interplay, or dynamic, of what we falsely dichotomize as 'nature and nurture', as if they were two separate things. This adaptive power is one reason why our children and their descendents might dare, against the odds, to hope for some kind of civilized future existence incorporating a new covenant between science and society.

'I would know my shadow and my light, so shall I at last be whole.'
Michael Tippett[128]

Respect for science is on trial in today's world. This is not only trial by soundbite but also, more to the point, trial by our deepest fears and imaginings.[129,130] Paradoxically, it is the same world where science has made it possible for all children to be wanted children[131] — perhaps the greatest of all blessings — where the economic running is being made by scientifically minded competitors, and where scientific skills and knowledge are crucial to meeting the growing threats from poverty, war, terrorism, environmental change, and new disease epidemics.[132,133]

Like it or not, science and technology are increasingly powerful tools for good and evil. Human societies, especially those with democratic aspirations, need some understanding of the tools they use. If today's democracies are to survive as democracies of any kind they will need to find ways of alleviating the widespread, profound, and dangerous confusion[134,135] about what science is and what it is not, and about the value of science to society. That value includes the human value of the scientific ideal, meaning the ideal in the sense discussed in Parts I and II of this series[136] — a value now largely neglected and perhaps even largely unrecognized by today's societies, as expressed officially by trends in science policymaking and auditing. I shall argue that this puts us in far greater peril than is commonly believed. There is plenty of lip service to the ideal, but society's actual incentives are increasingly stacked against it.

The rest of this book will try to sketch what seems to be involved. Alongside well known themes there are some new twists, coming from recent discoveries in linguistics and palaeoclimatology and from insights into perception and cognition, plus evidence from palaeoanatomy and genetics. There are increasingly clear implications not only for science policymaking and auditing but also for education, and for scientists' professional codes of conduct.

Ideal and method

I shall refer later to the sceptical questions asked by thoughtful and intelligent non-scientists. Some of those questions indicate a confusion for which we as scientists are in part to blame: a confusion between the scientific ideal, on the one hand, and human attempts to approach it on the other. These two very different things tend to be lumped together when speaking of 'science' or 'the scientific method'.

Even professional historians of science have sometimes lost sight of the ideal in their attempts to understand the complexities, imperfections, and fallibilities — indeed, the sheer stubborn difficulties — of human attempts to approach the ideal while struggling with uncertainty at the periphery of scientific knowledge. That struggle, indeed the whole sociology and psychology of research, is an important but separate aspect of science.[137] It is something that needs to be clearly distinguished from the scientific ideal. It involves of course human error, moral issues, varying standards of personal behaviour, power games played by scientists and non-scientists, bandwagon effects and so called paradigm changes, ever increasing cultural and commercial pressures, varying levels of numinous or religious feeling, and certainly no single, rigid, infallible methodology. Although there are good practical working rules tested by harsh experience, 'the scientific method' — unlike the scientific ideal — is not, never was, nor is ever likely to be, a rigidly defined entity let alone something that is simple to explain.

Let me try to put the last point more sharply. It is a dangerous illusion to think that there is a rigidly and explicitly defined 'method' guaranteed to produce accurate scientific judgments on demand, let alone to do so before the next quarterly financial report. If there were such a method, then science would be best turned over to computers. Anyone who has done significant scientific research knows that there is no generally applicable 'method' in that sense, especially when we are dealing with the unknown and the unpredictable — as with, for example, the evolutionary response of bacteria to antibiotics,[132] and the emergence of new disease agents in response to pollution.[138,139] Disease agents know nothing of financial reports. They are massively parallel problem solvers that in some sense know about, and try to adapt to, the temperatures, chemicals, and life forms in their changing environments.

There is a fundamental reason why scientific 'method' cannot be rigidly and legalistically defined. If you accept the hypothesis that both science and ordinary perception work by model-fitting, and therefore involve combinatorial tree pruning, then it follows, for the reasons discussed in Parts I and II — including the largeness of combinatorially large numbers — that even the most rigorous, the most meticulous scientific thinking has an inescapable unconscious component. It is not just that some of the modelling assumptions happen to be unconscious: a good many are bound to be unconscious. The 'walking lights' phenomenon is a simple but sufficient illustration,[136] and there are countless others.[140]

The model-fitting hypothesis explains why scientific and technological breakthroughs, and much ordinary scientific progress as well, often come from exposing, from making conscious, a previously unconscious assumption, from breaking out of what psychologists call a mental tunnel.[140,141] This means unpruning some branch of a combinatorially large tree of possibilities.[142] If the branch comes from far enough down the tree then we tend to speak of a breakthrough or even a paradigm change.[141]

I want to make a case for talking less often about the scientific method, in public at least, and more often about the scientific ideal. As already hinted, remembering the ideal is important for a simple reason that transcends technicalities. Forgetting it is likely to have catastrophic consequences for humankind, for our increasingly crowded planet and ourselves. New evidence about our distant past underlines this point, as will be seen shortly. And a wider appreciation of the scientific ideal and its significance is surely attainable, because it is fundamentally a simple matter, and because there is genuine public interest. Such appreciation could help to answer or forestall the sceptical questions asked by thoughtful and intelligent non-scientists. It could help to counter the widespread, and in some ways understandable, talk about the end of science, the failure of science, the arbitrariness, the inhumanity, the imperialism, the evil, the loathsomeness of science,[143] and so forth.

There is, of course, nothing arcane or technically complicated about the scientific ideal. Difficult though it may be to approach, it should be easy to explain — to ourselves, to our students, and to others. Such explanations have been given before,[311] and they will have to be given again.

One might try saying, for instance, that respect for the scientific ideal is like caution in buying a used car,[135] or like the attitude of a Miss Marple trying to solve a murder mystery. I was going to say Sherlock Holmes, except that he is far too sure about seeing all the possibilities. It is like the sceptical juror's attitude in the film *Twelve Angry Men*, the juror who insisted on taking another look at the evidence in a murder trial when everyone else thought they knew the truth. One might say that it is like Spock's attitude in *Star Trek*, if you like *Star Trek*, though nothing to do with the flashing lights[144] — and nothing to do with comic strip pictures of spitting sparks, bubbling beakers, monster mutants, and mad scientists.

Respect for the scientific ideal is something very sane, close to common sense even though much more careful.[145] It is an attitude that tries hard to keep an open mind while deploying logical thinking as carefully as possible. It puts up with nagging uncertainty. It is willing to admit ignorance. It shows humility in the face of the unknown, and avoids claiming that science can solve all our problems. It avoids prior judgments about candidate theories or hypotheses, that is, about candidate models, and it avoids prior judgments about methodologies and domains of applicability, apart from giving primacy to the coherence and self consistency of a model and its goodness of fit to experimental data. It is sceptical about any other reasons to favour a model, apart from the cautious application of Occam's razor, or explanatory parsimony, the principle that a model should be no more complicated than necessary.

It asks, what happens to the goodness of fit when new data become available? Does the whole thing withstand being looked at from another viewpoint? Does it withstand all the consistency checks anyone can think of? (That is why *thought experiments*,[146] as well as mathematics and computer simulations,[136,142,147] are so important in science.) How accurate is the fit? How good are the data? Does the theory, the model being tested, need to be changed, or thrown out altogether — do we need some large or small paradigm change, or novel viewpoint as it used to be called — or does the experimental error or the experimental concept need further investigation? Am I measuring what I think I am measuring?

Just as with the model-fitting process underlying ordinary perception, these are all questions about accuracy or goodness of fit, and about repeated checking in different ways. They are about taking yet another look from yet another angle[146] or, so to speak, listening or feeling as well as looking, and not about any absolute and knowably final truth of the theory. 'If it looks like a duck, quacks like a duck, and waddles like a duck, let's see if it swims like a duck and dives like a duck.' Even in those remarkable cases in physics where a beautifully simple theory repeatedly fits high precision data to many decimal places, including data obtained after theoretical predictions are made, we can never — if we respect the scientific ideal — claim to know with certainty that any such theory represents an absolute truth, even though we can reasonably and provisionally say that such a theory must, in some sense, be close to reality, or 'close to the truth'.[148]

It is indeed remarkable — not to say awesome — how well Occam's razor seems to work in some cases at least: how reliable, accurate, and widely applicable a simple model can be, and how beautiful and insightful. Einstein's gravitational theory is a good example, and a supremely beautiful one.[149] There can be no doubt that the skilful use of Occam's razor, and the *faith* in Occam's razor, has had a crucial role in the discovery of such models.[147,149,150] But none of this implies the possibility of access to a final and absolute truth that is known for certain or could, even in principle, be known for certain.

I shall return to this point because, though it may sound to some like philosophical hair splitting and to others like repeating the obvious, and though it has often been made before, the point is too important to be left aside. It is an essential part of what I am calling the scientific ideal, and I believe central to solving the problems labelled 'science wars' and 'public understanding', beginning at primary school level.[151] I think the point should be made as often and as cogently as possible, especially by teachers and by scientists in the public eye. In today's conditions it is arguably the most crucial single point to get over to non-scientists, when trying to improve the public understanding of science and when trying to discourage the misuse of science, as with

For reasons to be explained I think it is the point whose neglect, in the long run, most deeply and dangerously undermines respect for the scientific ideal and reduces the value of the ideal to society, not least the human value in a far-reaching sense.

The value of the scientific ideal

But what is it, then, this value to society, this human value, of the scientific ideal? Contrary to popular mythology, it is not only the value of cheap long-distance communication, painless dentistry, heart pacemakers, and the like. It is not only the value of the invisible science base, the unmeasurable infrastructure of tacit skills and mental flexibility[152] required to reach and make use of tomorrow's new knowledge, new understanding, and new technologies, a prerequisite to future developments of practical and economic value — such as the maintenance or improvement of food safety, the mitigation or prevention of the new disease epidemics, the humane avoidance of overpopulation and environmental stress, the development of robustness, security, maintainability, reliability, and auditability of computer software and electronic transaction systems,[153,154] the efficient and sustainable use of energy and other resources,[155,156] the containment of terrorism,[157] the early detection of environmental change whether natural or manmade — the value of good science and technology as our eyes and ears on an uncertain future, without which our heads, and our leaders' heads, will be firmly buried in the sand, at great future cost.[131,132,158] Nor indeed is it only the invisible and unmeasurable cultural value, the value of the intellectual thrill and astonishment of great discoveries and great leaps of the imagination, and the spiritual value of something that transcends the individual:

> Then felt I like some watcher of the skies
> When a new planet swims into his ken ... — John Keats[159]

Of course, it is all of these. But it is also something still less visible and still less measurable, though still more crucial and still more valuable, in a hard economic sense, increasingly forgotten in the obsession with short-term wealth creation. It is the value, beyond price, of respect for the scientific ideal, if such respect can be maintained, as a moderating or countervailing force, or if you will an insurance, against renewed cycles of social chaos and totalitarian repression in a world full of modern weapons, biological, physical, chemical, psychological, information-technological, and economic[155] — an insurance against what today's politicians might call wealth *destruction* on a gigantic scale, a scale incalculably greater than the recent wealth destruction by food safety scares, itself caused in large measure by disrespect for the scientific ideal.[139,270]

This is one of the points missed by those who see wealth creation as the sole justification of science. I am talking about an insurance against wealth destruction on the scale of gross national products, an insurance against the breakdown of democracy itself, of government by consent, of free trade and personal prosperity — the breakdown of the increasingly fragile economic, technological, and psychological infrastructures of modern human societies — an insurance whose premiums are dwarfed by the cost of the disasters insured against. It is a long term insurance whose value might command significant public understanding, if explained well enough. It has not, I think, been explained nearly well enough in recent years, because its value, though long recognized by careful thinkers,[160] now seems to be forgotten not only in popular mythology but also, I shall argue, in today's official science policymaking, much of which powerfully discourages the scientific ideal.

This forgetfulness seems to be connected in part with the workings of the short sighted, not to say blind, international market forces that seem to dominate our situation today, and to which I shall also refer, the very forces whose enormous strength makes us forget that they too are vulnerable — that the markets themselves depend for their wealth creating potential on the avoidance of social chaos and totalitarian repression.

But how can respect for the scientific ideal be socially stabilizing, rather than destabilizing as some would now have us believe? As long recognized by careful thinkers, something very fundamental is involved, something both visible and invisible. It is something about our own human nature that we seem close to understanding quite well, and that in any case we need to understand as well as possible. It is a matter of ubiquitous psychological realities, of our unalterable genetic inheritance,[161,162] part of what our politicians both underestimate[163] and perilously exploit. Respect for the scientific ideal cannot solve all our problems, but it can help with 'clearing space to speak of the unspeakable',[164] with tipping the balance — as has already happened so remarkably in recent centuries — toward understanding, moderating, and redirecting some of the most terrible and potent forces that lead to social instability.

These forces manifest themselves most plainly, as everyone knows, in the phenomena called bigotry and superstition, sectarianism and racism, scapegoating and witch hunting,[165] kamikaze terrorism and other forms of human sacrifice,[166] and genocidal warfare. They are forces whose crosscultural presence and whose potential for social catastrophe have been amply and repeatedly demonstrated throughout history, as well as in recent living memory. I shall hypothesize that they involve what is usually called 'instinctive' behaviour,[167] including unconscious cultural influence — more aptly nature–nurture or genetic–memetic[168] interactions, the intricate, inextricable interplay of genome and culture[161,167–171] — and I assume that these forces are latent in everyone and could easily be powerful enough to destroy democracies and free market economies of the type now familiar, which, throughout human existence, have not, after all, been among the usual types of human society,[172] especially under environmental stress.

These forces are protean: they are taking new forms and we must not think that understanding them is trivial. But I shall argue, too, that our species' astonishing adaptability leaves room for an optimism that is not naive. As has happened before, new understanding can take us on new journeys, in directions previously undreamt of.

Language and climate

What then is fundamental? To get a clearer view of this, I must digress on language and climate. We possess new and decisive evidence on both. First, language is far more ancient than we used to think — specifically, far more ancient than the visual arts of the Upper Palaeolithic, more like hundreds than tens of millennia. Second, our prehistoric ancestors, or some of them at least, had to survive larger, more rapid, and more frequent climate fluctuations than we used to think. There was a highly unstable climate regime throughout much of our ancestors' human and prehuman existence, suggesting more strongly than ever that climate fluctuations were important for our ancestors' development.

By prehuman existence I mean a fully bipedal, fully ground dwelling existence, which as far as the fossil record can tell us dates from around the beginning of the unstable climate regime, the Pleistocene, roughly 2000 millennia ago. It was probably then that the ability to abandon shrinking forests and migrate freely began to compensate for greater exposure to predators.[173] The record also shows, beginning near that time, the first of two periods of strikingly rapid brain expansion; *see* Fig. 1. This can be well explained in terms of the intensified selective pressures toward ever larger group sizes that must, inevitably, have arisen at that time, from the exposure to predators even if from no other cause (e.g. Refs. 166, 173, and many references therein).

[[Fig. 1 (`lucidity-figP1.gif`) near here; refs. 173,174 in caption]]]

By human as distinct from prehuman existence I mean language speaking existence. Despite lingering controversy it is now clear, from evidence to be reviewed shortly, that the human language ability resides in genetic memory. This suggests in turn that language and brain are likely to have evolved together over a timespan sufficient for substantial genetic change, probably hundreds of millennia at least. Such co-evolution can explain the second period of rapid brain expansion, seen at the left of Fig. 1, what Christopher Wills[161] has called the 'runaway brain' phenomenon.

The first period of brain expansion, from roughly 2000 millennia ago, seems likely to have been associated with a preadaptation for language, rather than with anything like language as we know it. Such preadaptation seems likely to have involved vocal as well as visual (facial and gestural) communication — all highly advantageous under the pressure to increase group size, even if for no other purposes, at first, than social bonding and simple forms of signalling, as observed among today's non-human primates.[184] Ref. 173 makes a cogent palaeoanatomical case for just such a preadaptation, pointing out first of all that our characteristic brain asymmetries, illustrated in Fig. 2, were already present 2000 millennia ago, even though brain size was much smaller, suggesting an early trend toward elaborate vocalization and auditory perception. Furthermore, the case continues, other anatomical features — including those related to bipedalism — have strong implications not only for vocalization and hand–eye coordination but also for diet and metabolism, and for infantile brain development. Bipedalism implies a small birth canal and early birth, the more so as brain size increases, hence increasingly early exposure of infants to a rich sensory input. Versatile brain development would thus have been favoured in a number of ways, with far-reaching implications for social interactions and genetic–memetic evolution. All this seems to fit into a self consistent picture of group dynamics and evolution under the extreme pressure to increase group size, with a high premium on intelligence and especially social intelligence.

[[Fig. 2 (`lucidity-figP2.gif`) near here]]; ref. 175 cited in caption]]]

Jumping to more recent times we may note three lines of evidence, independent of the foregoing, all indicating that language was well developed by a hundred millennia ago at the latest. First, there are the genetics and comparative linguistics of modern humans across the globe, especially in culturally isolated pockets, outside the major language groups, in places like Papua New Guinea. The implication is that a language ability close to today's must have been fully formed by that time, if not earlier.[167] The fossil record, now beginning to include evidence from DNA sequencing, suggests that the worldwide spread of the human genome — the spread of our species from its likely original home in Africa — must have taken a hundred millennia or more.

Second and third, the genetic basis of language has been independently confirmed not only by increasingly clearcut psycholinguistic research results[176] but also, very recently, by another piece of evidence that is decisive in itself, concerning what linguists call creolization, or nativization. This is the construction, from fragmentary raw material, of a syntactically complete, syntactically consistent new language by a single generation of children younger than 7 years or so — naturally and spontaneously, as part of their rehearsal for 'real life', the deadly serious rehearsal that we call juvenile play.[177]

A case of creolization has now been observed and documented, in full detail, for the first time.[167,178] The story is fascinating and compelling. In Nicaragua, in 1979, there was a change of government that brought deaf children together in a new State school system, after long social isolation from other deaf people. The result, within just a few years, was the creation of two new sign languages the prior absence of which is well documented: first a pidgin-like sign language, syntactically feeble, inconsistent, and unstable, like other pidgins, and second a creole-like sign language, syntactically powerful, consistent, and stable, like other creoles, having the full range of syntactic or grammatical devices. The creole is now displacing the pidgin. Close observation of the children's behaviour over a number of years, including systematic tests recorded on videotape, has established that the pidgin was created by children older than about 7 years, and the creole subsequently by those younger. The only linguistic input to the younger children was the fragmentary raw material provided by the older children's pidgin. There was no way that there could have been significant linguistic input from adults.

Here then is the clearest possible demonstration that, astonishing as it may seem, genetic memory contains, implicitly, the complete syntactic machinery of language. Or, more carefully stated, genetic memory contains the complete wherewithal — the seeds of the self assembling, self organizing, yet input-sensitive components — from which to build that syntactic machinery.

Creolization, remarkable though it is, need not surprise an observant parent. English children when small tend to say 'I keeped mouses' before learning to say 'I kept mice'. As Noam Chomsky pointed out long ago, it is not syntactic function and syntactic consistency that young children have to learn from the language they hear or see around them. Rather, what they have to learn is the superficial form and above all the irregularities of the language, the culturally evolved *departures* from syntactic consistency. As Steven Pinker[167] aptly puts it, 'a three-year-old ... is a grammatical genius'.

Now the language ability, like other functional abilities of living organisms, must have developed in parallel with its most basic uses, as language became ever more critical to survival in increasingly large groups or tribes. In the living world, functional abilities develop through use, and only through use; and they atrophy through lack of use. Sooner or later, the basic uses of language must have included, for instance, what we call storytelling — again part of, and growing from, juvenile play and again rehearsing for real life, and doing so in more than one way — not only expanding the ability to imagine or remember real situations that might be important to survival, such as, for instance, the climate and vegetation of past centuries,[179] but also in the process developing linguistic skill. Juvenile play in any species develops the abilities and skills of that species. It is no accident that young children love stories — narratives if you prefer — and will create them spontaneously, just as kittens propel small objects in order to chase them.[180] Neither thing needs to be taught, and both things are essential to the survival of the species.

Sooner or later, therefore, in our ancestors' evolution, linguistic skills must have become as important as any other survival skill, hunting or gathering or anything else. In particular, as has often been suggested, linguistic skills must have been intimately part of what we call social skills: what grows not only from storytelling but also from making friends, allies, enemies, jokes, love — what grows from, what is driven by, the imperatives of group survival and social cohesion. Social skills must have included forms or precursors of what we now call rhetoric and advocacy[181] and the building, reinforcement, and exploitation of belief systems. Such skills would have been strongly selected for by the competition for mates and for varieties of social influence within a group or tribe; and that ongoing competition must have been a continual and potent driving force for linguistic evolution, genetic and memetic, a force conspicuously at work today.[167,182] So the skills we call rhetoric and advocacy, in one form or another, must themselves have been survival skills and intimately part of the use and development of language itself — notwithstanding our tendency to think of rhetoric and advocacy as recent inventions, along with the associated cognitive symbolism.

Notice by the way that none of these uses of language need have left the slightest archaeological trace. The impermanence of sound waves, and of visual signals too, is sometimes forgotten in the heat of controversy. Furthermore, our powers of cognitive symbolism — including the unconscious power of abstraction discussed in Part II — are so intimately bound up with unconscious levels of perception and cognition that they must have had origins far more ancient, even, than the timespan of Fig. 1.

All this, of course, was already implicit in the line of argument developed in Parts I and II. It is not only ourselves, but also monkeys and other creatures, that can avoid a charging rhinoceros and therefore must, presumably, have unconscious model-fitting abilities. Language had no need to build cognitive symbolism from scratch; it could develop, and make connections to, unconscious symbolic structures already there.

The possibility thus suggested that the linguistic arts became highly developed long before the recorded visual arts, and that they were crucial to tribal development, cohesion, memory,[179] and belief systems[166] provides an interesting variant of, or alternative to, pictures of cognitive development such as that suggested in Ref. 183, which approaches the problem from an archaeological perspective. Visual symbolism recorded in art objects like beads and bracelets, first appearing in the Upper Palaeolithic archaeological record a mere 40 to 60 millennia ago, could have been late developing precisely *because* the linguistic or oral arts were already rich enough to support tribal cohesion and competitiveness. They could have been rich enough either on their own, or, more likely, complemented by unrecorded, but remembered, visual arts of mimicry and dance.

The early development of linguistic arts and skills, including storytelling, being presumably central to survival, would in any case have been intimately part of, and central to, the co-evolution of brain and language — part of the whole biological point, or if you will, 'purpose', of that co-evolution under the continuing, and longstanding, selective pressures for tribal cohesion and competitiveness, pressures that must have been acute for at least half the timespan of Fig.1, i.e. for more like thousands than tens of millennia. And the linguistic or oral arts, plus mimicry and dance, would have been among the most eminently *portable* art forms for a tribe on the move — long before the Upper Palaeolithic.

And tribal competitiveness must have involved, of course, not just social cohesion, collective memory, improved hunting skills, and ways of coping with predators, but also — inevitably — warmaking skills.[174] There must have been territorial warfare, including genocidal warfare, beginning on the small scale observed today among chimpanzees[184] but developing formidably as language and rhetoric developed, allowing tribes to expand yet cohere. And on top of all the other selective pressures — putting a higher premium on warmaking — would have been the forced migrations due to the unstable climate itself.

Such pressures must have been especially intense during the final hundred millennia or so, the final spurt at the extreme left of Fig. 3, during which migration took many of our ancestors out of Africa into or through regions strongly affected by climate instability. New palaeoclimatological evidence, at unprecedentedly sharp time resolutions, has revealed many large and rapid fluctuations during that time. In some parts of the world at least, there were climatic temperature changes of the order of several degrees Celsius 'within decades'.[185] There were large oscillations with periods of the order of 2 centuries.[179] And again and again there were large changes in sea level, including episodes of sea level rise at rates up to about 3 metres per century. At such times and places the environmental change within an individual's lifetime would have been far bigger, and swifter, than the changes now being discussed in connection with possible manmade global warming. Together with the vagaries of chaotic ecodynamics[186] and of human population growth, the climate fluctuations must have kept tribes on the move in what became a global scale diffusion, almost a random walk in the technical sense of the term, in an unwritten saga of growth, famine, migration, and warfare. As Ref. 173 reminds us — and equally cogently Refs. 161, 166, and 174 among others — the runaway brain evolution seen at the left of Fig. 1 is probably the signature of, quite literally, an 'evolutionary arms race'.

The behavioural abilities and potentials that most powerfully coped with this situation — that produced the largest, best coordinated, and most formidable tribes — must have been well established, and long established, in genetic memory by the time the climate turned warmer and more stable about ten millennia ago, leading to the first large agricultural communities.[191] Ten millennia is little more than an instant of genetic evolution. We may reasonably assume that along with formidable linguistic skills there must have evolved, by then, our powerful sense of truth and falsehood, and an ability to accept as absolute truth the tribe's belief system, reinforced in times of need by the word of a strong leader — giving leaders the power to galvanize followers into action while assuaging their fear of the unknown.[166,174] As language is ancient, so is conviction politics. A tribe thus equipped would have had overwhelming advantages over any that were not. The leaders' claim, implicit or explicit, to be the mouthpiece of absolute truth would naturally, in times of war, have implicitly or explicitly portrayed any deviant beliefs, including a competing tribe's beliefs or alleged beliefs, as absolutely false and in need of extermination. Numinous or visionary experience, more probable in times of famine or other hardship, would have served to reinforce such claims. And there can be little doubt, as already suggested, that we are genetically much the same now as ten millennia ago: the divine and the demonic must surely be, for some portion of the population, just as real and intense today as they were then.

Hypercredulity and the urge to dichotomize

From the evidence and the arguments just reviewed, it should be no surprise to find today, in genetic memory, showing itself in many cultures, not only a capacity for such things as love, altruism, wit, invective, poetry, rhetoric, and visionary experience — whose latency in genetic memory we can now routinely demonstrate through mind altering drugs, more easily than through the natural mechanisms of stress and starvation (*see* also ref. 203) — but also a capacity, a tendency, an urge, a longing, a profound need, stronger in some individuals than in others, to believe in some unique Absolute Truth or Answer to Everything, regardless of logical coherence or supporting evidence.

There is a recognisable, indeed conspicuous, behaviour pattern here,[134,135] on which I want to focus attention, with, among other things, scientists' professional codes of conduct in mind. It is a meme susceptibility if you will, a behavioural ability with a powerful and deep-rooted genetic underpinning or genetic component. We need a name for it, if possible a neutral, non-confrontational, self explanatory name, a non-partisan name that helps dispassionate discussion and steers clear of old feuds, clichés and distortions, that helps us to grasp, to understand, something of what is happening in today's world, and to understand the new dangers we face. The best I can come up with is 'hypercredulity', or 'hypercredulity instinct'.[187] The behaviour pattern in question seems to go beyond ordinary credulity, gullibility or mental laziness, and beyond the ordinary susceptibility to mental tunnelling or cognitive illusion.[140,188]

The likely importance of such behaviour to our ancestors' survival explains, also, why human language and cognition are so strong on feelings of truth and falsehood yet so weak on logical consistency checking — especially when compared with, say, the relatively tight, but unconscious, consistency constraints on visual perception discussed in Parts I and II — why self-contradictory terms like 'heteroactive barber', meaning a barber who shaves those and only those who do not shave themselves, are not intuitively nonsensical even though actually nonsensical.[136]

Bound up with all this seems to be the equally conspicuous, and peculiarly powerful, human urge to dichotomize or polarize, to make two-way distinctions, to see things in black and white or as absolutely true or absolutely false, reflecting not only the 'we or they' of tribal conflict but also the prelinguistic dichotomies like 'edible or inedible', 'fight or flight', and 'male or female', and tending to spill in other directions as well:

> Don't equivocate! Either it's Nature or it's Nurture.
>
> Whaddaya mean, yes *and* no? Give me a straight answer.
>
> You can't have it both ways: either you're for God or you're for Satan.
>
> Just tell us The Truth! Either X is safe or it isn't.

Aristotle's law of the logically excluded middle is replaced by the urge to annihilate any kind of middle. Our politicians' exploitation of, or struggle against, such behaviour patterns can be seen every day. Even well educated, thoughtful, intelligent people who can see that 'nature or nurture', for instance, is a false dichotomy still tend to say, as I have observed on countless occasions, that it's a matter of some percentage of one and some percentage of the other. As geneticists are quick to point out nowadays,[129,161,171] that is complete nonsense — a bit like talking about a lock and key mechanism that is 30% lock and 70% key. No simple analogy can capture the intricacy, complexity, and subtlety, the sheer richness, the vast hidden potential, the combinatorially large 'phase space' of possibilities[187] of the genetic–memetic dynamic, in which both aspects are essential.

Here of course things get delicate, very close to the bone. If you will, I am using the words 'hypercredulity' and 'dichotomization' — I wish I could think of two shorter, yet self-explanatory words — as caricatures of a sort, as ways of highlighting a particular aspect, you might say a primitive extreme, of our complex nature that needs to be recognized. I am not suggesting that either word captures everything about the vast edifices of today's human belief systems, including what you might fairly regard as their more civilized and spiritually necessary aspects. Indeed I want to draw a sharp distinction between, on the one hand, hypercredulity understood in the sense of the primitive urge to believe in a unique Absolute Truth and Answer to Everything — no alternative to which can be tolerated and no aspect questioned — and, on the other hand, the need for 'something to believe in' understood in a more democratic way, in the sense of a personal truth or faith that may be shared with others but does not demand to be imposed on others.

This is a distinction that our ancestors could not have been in any position to make. Throughout most of prehistory, as we call it, a typical tribe would have had to stick together or be wiped out. Indeed, as already noted, the selective pressure to stick together must have been prelinguistic, and unremittingly intense from the time, about halfway through Fig. 1, that our ancestors became ground dwelling, bipedal, continuously exposed to large predators and also, probably, *benefiting* from the same predators through the leftover carcasses of other large animals killed by them, supplying some of the high quality diet for expanding, metabolically greedy, energy-hungry brains.[173] Ref. 166 suggests that aspects of the divine and the demonic, long enshrined in what we call pagan religion and mythology — the obsession with blood rites, the worship of deities that are both fickle benefactors and devouring monsters, the ecstasy of war and human sacrifice — could well have had their beginnings in those very circumstances, long, long before the existence of language as we know it. And so too, perhaps, does yet another conspicuous and widespread human behaviour pattern — the wordless, mindless urge to gamble, to tickle the monster's tail,[189] to dare fate, to risk everything for Victory, Power, and Glory — or even just for personal gain.

The dark side of the Platonic

One has to marvel at the extraordinary moment of history we live in, and at our species' extraordinary adaptability. It is a remarkable testament to that adaptability, and to the power of cultural evolution, that any of us now dare make the distinction between hypercredulity and personal faith despite being genetically almost the same as ten millennia ago. The distinction is now understood and the making of it now tolerated more widely, perhaps, than ever before in human history and prehistory.[172] Along with many others I would argue that a major reason for this degree of toleration, and for being able to make the distinction at all, is respect — implicit or explicit, acknowledged or unacknowledged — for the scientific ideal or its equivalent, for science not as arrogance but as humility, not as absolute truth but as rational, empirical, and sceptical thinking: respect for taking experimental evidence seriously, and recognition that any claim to infallible knowledge is, indeed, deeply irrational. The physicist Max Born put the point sharply but well: 'I believe that ideas such as absolute certitude, absolute exactness, final truth, etc., are figments of the imagination which should not be admissible in any field of science ... This *loosening of thinking* [Born's emphasis] seems to me to be the greatest blessing which modern science has given to us. For the belief in a single truth and in being the possessor thereof is the root cause of all evil in the world.'[190] Jacob Bronowski, paying his respects at Auschwitz, put the last point even more sharply: 'This is where people were turned into numbers. Into this pond were flushed the ashes of some four million people. And that was not done by gas. It was done by arrogance ... This is what men do when they aspire to the knowledge of gods.'[191]

I am suggesting, then, that recognition of the distinction between hypercredulity and personal faith, and social toleration of those making the distinction — which toleration always hangs, perilously, in the balance — might once again gain ground if respect for the scientific ideal were once again to gain ground. Such recognition, toleration, and respect are surely fundamental to our chances of a civilized future; and it is precisely here — as I shall try to argue as cogently as I can — that there are implications for scientists' professional codes of conduct.

But recognition of the distinction means recognition, first of all, of hypercredulity itself. If, as is still fashionable in some circles — and I have encountered this even among scientific colleagues — if you are prepared to dismiss the sort of evidence I have cited and claim that it's all down to culture, a hundred percent nurture without any nature, that there is no such thing as genetic–memetic evolution leading to instinctive behaviour, that infant minds are blank slates and that tolerance is just a matter of a culture deciding to be tolerant — whatever that might mean — then consider how to explain various observed phenomena.

Consider for instance the debate on the right to die. Consider indeed the observation that such a debate exists in, among other countries, the USA, in a culture born of escape from persecution and professing personal liberty as its highest ideal. This culture of personal liberty, proclaimed throughout the anthem *America* and in countless political slogans, seems unable to prevent the persecution, today, of individuals for holding to a personal faith that declares no threat to others and is nothing but a sure knowledge of readiness to die at a chosen time, alone or in chosen company, without harming others, and with a felt sense of rightness or even sacredness. The example is noteworthy because 'sure knowledge', in the sense of a personal truth or faith, has such an outstandingly simple, clear, and testable meaning — manifested by willingness to press a switch that you know will lead to your own death.

Such sureness, such personal faith, is not only testable; it has also been tested, in recent years, through the work of pioneers like Dr Jack Kevorkian of Detroit, Michigan, USA. At the cost of his own medical career, Kevorkian has made available to ordinary people who consult him the means to die voluntarily, peacefully, and with dignity, and at a chosen time, alone or in chosen company, by pressing a switch — after due counselling, and with assurances up to the last moment that a change of mind is no problem. Kevorkian, though never himself pressing the fatal switch, has been called a 'murderer'; and he and his patients have been subjected to legal and newsmedia harassment, including police intrusion at the family deathbed and actual murder charges, acquittal from which led to changes in the law prior to further attempts to convict.

> *Note added April 1999:* I can no longer assert that Kevorkian 'never' himself took fatal action. On 17 September 1998 he administered a lethal injection at the request of a paralyzed or near-paralyzed terminal patient. More detail in Note 192*a*.

These events, all on the record,[192,193] well illustrate the power of what I am calling hypercredulous belief, even when held by a small minority of the members of a society. The individuals making the accusations of murder with such prodigious assurance [long before 17 September 1998] appear to be driven by belief in a unique, infallible, and unquestionable absolute truth, having the force of absolute authority over others even to the point of conferring the power of life and death over them — the power of death in the form of capital punishment,[193] and the power of life in the form of psychological or physical torture: the compulsory prolongation of grossly humiliating indignity or intractable chronic pain, twenty-four hours of terrifying agony each day. The individuals seeking to exercise such power, citizens of the 'sweet land of liberty', as the anthem has it, would no doubt profess belief in freedom, democracy, and individual human rights including the sanctity of life. Such doublethink, or hypocrisy as the case may be, is strong evidence — either way — for the existence of an immensely powerful instinct, something having roots deep in genetic memory and more powerful in some individuals, and in some circumstances or sub-cultures, than any broader culture that weighs against it.

There is no lack of other examples. Consider today's best known form of voluntary human sacrifice.[166] Consider what it takes, if not hypercredulity, to become a kamikaze terrorist or suicide bomber — or martyr, depending on your viewpoint — literally, a bringer of the 'divine wind' to save your people, certain of heavenly bliss for exercising, in another way, the power of life and death over others. Again, consider the record on medieval witch hunting and its recent counterpart in the Chinese Cultural Revolution.[194] Consider the power, and evident deep-rootedness, beyond reason, of ordinary, commonplace racism and sectarian hatred. 'People discover race hatred the way lovers discover love. It always seems utterly new and fresh to the hater ... And, like love, race hatred always expresses itself in the same clichés, uttered as if the hater had discovered the principles of the universe.'[195] Indeed, what thing in genetic memory, what Answer to Everything awaiting fresh discovery, could have been more powerful in winning the evolutionary arms race suggested in Fig. 1, in galvanizing one tribe to exterminate another when the unstable climate forced them together? We may yet learn to call this thing the dark side of the Platonic.

Again, consider the power of the belief, exploited by tycoons and flying in the face of the evidence, that Market Forces are the Answer to Everything — as distinct from the reasonable proposition, happily gaining ground today, that market forces are useful for some things[155,156,158] though not for others.[196] Consider the related belief that Everything Must Be Measured, if not in numbers of dollars then in numbers called 'performance', 'productivity', etc., part of an 'audit culture'[197–200] that brooks no questioning — as distinct from the reasonable proposition that measurement and auditing are useful for some things though not for others. Again, consider the power of the belief, among intelligent, highly educated people, that language dictates thought — centuries old and still, as far as I know, passionately held in some parts of the academic world of postmodernism and so called political correctness — the appealingly simple idea that language *is* thought, that we are total and absolute slaves to our fickle and unstable semantics (Korzybski–Sapir–Whorf hypothesis), as distinct from the reasonable proposition that language, depending on how it is used, is a powerful tool for confusing or clarifying our thinking, and for inciting various kinds of behaviour, and that language has its more stable and its less stable aspects and its different timescales of evolution.[167] Ref. 135 gives further telling examples.

And beyond those, consider finally, if you will bear with me, the most straightforward, the plainest, simplest, and perhaps best documented example of all, that of the overtly fundamentalist religious cults that explicitly claim to have the Answer to Everything and succeed, again and again, in recruiting teenagers and young adults not only from the depths of third world poverty and repression but also from the affluent heartlands of the economically privileged Western democracies; and consider the record of personal testaments of those leaving the cults spontaneously or through 'deprogramming' or its modern variant, 'exit counselling'.[201,202]

Respect and humility

Exit counselling is something that deserves wider public attention, along with other group exercises for loosening thinking.[188] It is of interest not only to parents with sons and daughters in the fundamentalist cults, but also as illustrating Max Born's point — as a demonstration of how respect for the scientific ideal can loosen the grip of a preestablished hypercredulous belief. Exit counselling is non-coercive; and it does not talk about science as such, still less about flashing lights and bubbling beakers. Rather, it works by skilfully stimulating the cult member's instinctive interest in coherence and self consistency, in what hangs together and makes sense, in *what withstands consistency checking*. It assumes, often successfully, that 'victims of cults are not characteristically less intelligent than other people'.[202] Here is yet another illustration of our species' astonishing adaptability. It says again that respect for the scientific ideal, for coherence, self consistency, and experimental evidence, for what hangs together, can strengthen and encourage such adaptability in a way that is likely to be critical for our species' future.

Indeed, such respect is critical, I want to suggest, in more ways than the mere loosening of thinking, the mere weakening of the forces that push us toward overpopulation and tribal conflagration. There is a positive vision, a rational hope of alleviating our spiritual malaise — of finding ways to rediscover the sacred without confusing it with the absolute[203] — that can be put forward more persuasively than ever before. Respect for the scientific ideal can increase our chances of maintaining, and further developing, another kind of respect, born of growing understanding, and sheer wonder, a deeper respect for our own nature as part of the biosphere and as living organisms whose subtlety, sophistication, and vast complexity makes our most powerful electronic computers and other machines look like the crudest of kindergarten toys.[204,205]

We are beginning to learn such respect for what we used to call 'simple' organisms as well, such as bacteria. It is beginning to sink in that even a single bacterium, a prokaryotic cell, even one whose complete DNA sequence is known, is far too complicated to simulate in detail even on today's largest electronic computers — we can't even, in a computer simulation, fold all the proteins correctly yet, let alone accurately hypothesize how they all function in their thermally agitated environment — reminding us how implausible is the idea that Computers are the Answer to Everything and that robots will soon, in every respect, outstrip not only bacteria but also the human brain, a single one of whose tens of billions of neurons is a thousand or more times more massive, and orders of magnitude more complicated, than a single bacterium.[205] We are beginning to glimpse why such complexity and massively parallel architecture are crucial to human perception and cognition, which must deal with combinatorial largeness — and beginning to glimpse, as suggested earlier, where mathematics, music, poetry, rhetoric, and the other arts come from, and why rational and intuitive thought must, and do, work intimately together in many more ways than we can be conscious of. We are even beginning to learn, or relearn, what must have come naturally to our ancestors: respect for ecosystems and for the Earth as a whole. We are rediscovering such respect in new ways, through the wonderment of new insights, viewpoints, and vantage points inaccessible to our ancestors, through views of large and small worlds within worlds, through views of the cosmos, of quantum phenomena, of the biosphere, and of the Earth seen from space.

And respect for the scientific ideal, and the knowledge it has led to, have given us, for the first time in our existence, a rational hope of beginning to understand, of coming to terms with, of evolving more democratic ways of living with, our own instincts including the need for 'something to believe in'. Such understanding can add to the ways in which the energies unlocked by personal faith, courage, and enthusiasm can, and do, turn from destructive toward creative uses, toward ways of spiritual health that accept the naturalness, and the great value, of genetic–memetic diversity — of individual diversity and cultural diversity — ways that accept the different spiritual needs of different individuals and groups of individuals, ways that make room for reverence but distance themselves more and more surely from arrogance, bigotry, coercion, violence, and torture — from 'the belief in a single truth and in being the possessor thereof'.

Quantum mechanics and the Mind of God

Can such a vision, such a hope, be realized? As always, it hangs perilously in the balance. For the cultural evolution required will hardly be possible without social stability and freedom of information. This means survival of democracy in some form. And, for the reasons already rehearsed, the survival of any form of democracy must surely depend, among other things, on respect for the scientific ideal or something equivalent — on the willingness to be open to rationality, to take rationality seriously even though rationality is not, cannot be, the answer to everything. Echoing Born and Bronowski — and Friedrich von Spee, Thomas Ady, John Locke, Immanuel Kant, Karl Popper, Isaiah Berlin, Michael Walzer, Carl Sagan, and very many other careful thinkers down the centuries,[160,165,172,206] I am arguing that, whatever anyone may say about the evil of science or of scientists, a democracy that loses respect for the scientific ideal or its equivalent will quite literally be in mortal peril.

For without the respect for evidence, for coherence, for logic, the willingness to think again and to re-examine the evidence — and without the willingness to teach such things to our children[151] — what can hold the line against hypercredulous behaviour? What can hold the line against raw conviction politics, against primitive tribalism in all its political potency? What can stop torture or witch hunting when 'everyone knows' that exterminating witches is the Answer to Everything?[194] For 'witches' read any category you like: for some people today, it is already 'scientists'. Yet science is still our eyes and ears on an uncertain future.

Clearly, the peril is brought closer by the trend in journalism that treats science on an equal footing with pseudoscience, with no attempt to look for inconsistencies.[207] Clearly it is brought closer by the commercial and political moves against the free exchange of data and against scientific independence generally, to be discussed below. But the peril is also brought closer — for reasons I hope my discussion has made obvious — whenever a scientist is perceived as claiming to be the mouthpiece of absolute truth, or as suggesting that science might lead us to absolute truth or that scientists view science as the answer to everything or as a way to know the Mind of God.[134]

Whether or not a vague metaphor is intended, and whether or not such metaphors can be the private inspiration of great scientific achievement, is beside the point here. What is at stake is public perception and its mind sets, and the survival, or not, of public respect for the scientific ideal and the survival of democracy itself. I say this with the most profound personal respect for some of our greatest scientists, such as Albert Einstein. Einstein has often been quoted as using the 'Mind of God' metaphor or something like it. One feels that he got away with it because he showed respect and humility: 'the aspiration to truth is more precious than its assured possession'.[208]

I think most scientists recognize the problem and try to be careful about it, most of the time. However, it seems that we as scientists, or enthusiasts for science, are not always careful enough, especially when under political and newsmedia pressure and when tempted to use words like 'truth', 'certainty', and 'heresy' in the heat of debate. Once again we have a false dichotomy, and a supremely dangerous one: Science as Mere Opinion[209] versus Science as Absolute Truth.[134]

Take for instance some of today's pronouncements, and tacit assumptions, about quantum mechanics. They are strikingly similar to the pronouncements and tacit assumptions about classical physics in the late nineteenth century, which seemed to take for granted the absolute truth of a particular set of beautiful, high precision model building blocks, the principles of classical physics.[150,210] Just as those nineteenth century pronouncements ignored or played down known inconsistencies, like the electron spiral catastrophe in black-body radiation, so do some of today's pronouncements seem to ignore or play down what may prove to be inconsistencies between, for instance, quantum theory and gravitation theory at the Planck scale[211] of about 10^{-33} cm and, more important still, ignore or play down known points of inconsistency and vagueness in the quantum mechanical principles themselves, which have been well aired in the literature and to which I shall refer shortly. Indeed there seems to be a largely unspoken belief in the absolute truth, and completeness, of presently known quantum principles, or even of the subset of those principles presently expressible in precise mathematical form, describing what is called the unitary or hamiltonian evolution of wavefunctions or state vectors. Related to that subset, though not in a complete or fully consistent way[212,213] — and *see* the references to 'branching rates' below — is the hypothesis of many worlds or many universes. This says that 'all possible worlds are actual worlds',[212] in the sense that there are as many universes as there are quantum possibilities, a combinatorially large number to beat all combinatorially large numbers. I vividly remember hearing, around 1995, a well known physicist, someone who has done significant research in quantum theory and whose work I personally admire in many ways, saying clearly and forcefully in a television documentary that the many worlds hypothesis describes a reality about which we can be absolutely certain.

Such prodigious assurance can hardly be rational. I dare to hypothesize that it may instead be deeply instinctive — in a word, hypercredulous. It is to be contrasted with the more careful available discussions of quantum mechanical technicalities, which latter are fundamentally simple, mathematically speaking, even if their meaning is dizzyingly strange and the mathematical spaces dizzyingly and unimaginably large.[149,150,210–221] The many worlds hypothesis is not only untested, and arguably untestable in its present form, but also seems oblivious to the basis of science itself, including Occam's razor. All the well tested, accurate, reliable, hardcore scientific knowledge we possess — indeed, the very ideas of 'knowledge', 'reliability', and 'testing' — have been based, so far, on the hypothesis that we and our fellow creatures live in a single world, what I have been calling 'the' outside world, also 'reality', 'physical reality', 'physico-chemico-biological reality', 'the sensible universe', or what you will, a single world in which the same things and events can be observed by different people and the same experiments repeated by different people.[222] Although the single world hypothesis, like everything else, is not absolutely provable — and might somehow be shown one day to be untenable — it has withstood far more consistency checking than any other scientific modelmaking assumption. It is checked every time two people bump into each other in the street. The single world hypothesis has great simplifying power. It is arguably the most basic and powerful way in which we use Occam's razor, consciously as well as unconsciously. Abandoning it would call for very hard evidence indeed: far more than speculative hypotheses, making no precise predictions and supported by no experimental tests, about quantum mechanics outside its presently established domain of applicability.

Having dared to stick my neck into a controversy that is — oh sacrilege! — not even within my own research speciality, I must now return briefly to the topic of free will discussed in Part II. Why? Because our subjective experience of free will has been claimed, in a remarkable and interesting book published recently,[147] to be decisive experimental evidence in favour of the many worlds hypothesis — in the strong sense that all explanations of, or discussions of, free will within any single-world framework are 'pure gibberish' (p. 339 of Ref. 147). My reply to this depends on the arguments given in Part II. In brief, the claim just referred to is on the same footing as the claim, dealt with in Part II, that acausality illusions force the abandonment of ordinary physical causality principles. The point is that both claims ignore what is known, and easily checkable, about the workings of perception and cognition.

As was explained Part II, there is no need to regard free will as an illusion. Free will is a percept. It is no more and no less illusory than other percepts, like the perceived time of striking a piano key, or of hitting a fast moving ball. Such perceived times can be accurate to within milliseconds and anything but illusory, especially if you use them to become a great pianist or the Wimbledon Champion. All I am saying, and this is the point missed in Ref. 147 and in some other discussions of free will, is that subjective experiences are — can be none other than — properties of the brain's internal models or, in the language of Ref. 147 itself, properties of the brain's own 'virtual reality' apparatus, whose inputs include sensory data. Included in those internal model properties are the subjective experiences or qualia, i.e. the percepts, that we call the flow of time and the sequence of events, and equally the subjective experiences we call consciousness, free will, intentionality, planning, and action. The multiple possibilities of planned and intended actions can reside wholly within the brain's 'virtual reality' apparatus, and have no need of actual physical counterparts within a still vaster multiplicity of worlds or universes.

Let us return to the main point. Many worlds hypotheses or not, there seems to be a whole mystique built on assuming that the quantum principles, as used today, are the complete, final, absolute, and unquestionable truth, with an unlimited domain of applicability. That mystique is sometimes associated with the term 'quantum philosophy'.[215] The moment you ask what the principles are, you find that besides unitary evolution they include extremely vague notions of 'measurement' and 'observer', or of mysterious 'branching rates' or something equivalent,[217] for which there are no evolution equations or quantitative predictions. If you dare to point this out — that the lack of a clear, self consistent definition of an essential and fundamental element shows that something important must be missing from the theory — then you might be told that you are not even *allowed* to try to make the theory more nearly complete. It is taboo; it is not to be questioned. You must not dare to define such an essential, inscrutable element, because, as some might tell you, it defies the very rules of logic, or has its own arcane rules of 'quantum logic'.[215] Or you might be told almost the opposite, that the thing is forbidden because von Neumann's anti-hidden-variable theorem forbids it. This is what has been called the 'unspeakable' part of quantum mechanics.[146]

Why 'almost the opposite'? Von Neumann's theorem — or any other mathematical theorem — uses ordinary mathematics, and therefore ordinary logic, as distinct from 'quantum logic'. You do not need any expertise, therefore, to know that the theorem can have no bearing on something undefined and inscrutable. Mathematics is a sophisticated kind of consistency check. It tells you what follows from certain assumptions stated precisely. Wonderful and awesome though mathematics can be, it does not deal with the vague, the inscrutable, the ineffable. The points just made, including the irrelevance of von Neumann's theorem, have been cogently argued in Refs. 146 and 218 and elsewhere; *see* also Note 212. In many worlds and related theories, including those carrying the label 'decoherent histories' or 'consistent histories',[221] the vagueness arises in connection with the branching rates already mentioned. They are also called proliferation, splitting, pruning, or divergence rates;[147,217] and though talked about or written about they are not specified quantitatively, as already emphasized.

[[[Fig. 3 (`lucidity-figP3.gif`) near here; new ref. 223 is in figure caption]]]

Respect for the success of standard quantum mechanics compels us to say that in some sense, which no one fully understands — a point on which experts agree — it is a superbly good model. It is an astonishingly accurate and reliable model, of certain aspects of the outside world in an impressive range of circumstances. Among many examples, one of the simplest yet most striking, especially when regarded as evidence for a vast domain of applicability, is the so called blackbody radiation law, the curve plotted in Fig. 3, and, by implication, its quantum mechanical basis. The radiation law is described by a very simple equation. Yet it closely fits not only the relevant laboratory data but also very precise observations of what is called the cosmic background microwave radiation, consistent with cosmological models in which the radiation fills the whole universe and originated, in a thermodynamically reasonable way, at an early stage of the cosmic 'big bang'.[224] Ref. 223

gives the technical details concerning observational accuracy; note, however, that in Fig. 3 not only the observational points, but also their statistical error bars, are invisible — hidden well inside the thin curve. This is an example of the goodness of fit ignored by the cultural relativist and social constructivist philosophies of science.

Standard quantum mechanics correctly predicts, furthermore, phenomena so strongly counterintuitive that their repeated experimental confirmation is one of the greatest wonders of the world. The fact that computers work, most of the time, is wonder enough; and there are phenomena still more conspicuously strange, going under names like entanglement, nonlocality, quantum teleportation, or Einstein–Podolsky–Rosen–Bohm phenomena, now confirmed by many careful experiments.[149,212,216,310]

But respect for the scientific ideal says that, despite all this, we cannot accept any taboo on changes to the quantum principles if goodness of fit is preserved, as it can be in, literally, countless ways — a combinatorial infinity of ways. Most of these are frivolous in the sense of grossly violating Occam's razor, but there now exist a number of serious proposals, to change or add to quantum principles, in fairly simple ways that extend domains of applicability and define them more precisely, without abandoning the single world hypothesis, without relying on vague ideas about 'measurements', 'observers', 'branching rates', or their equivalent, without violating self consistency, and without affecting the goodness of fit to experimental data obtained so far.[146,220,225,226] These are what the late John Bell called 'sharp quantum theories'.[212] The main difficulty is finding experimental techniques that will begin to discriminate between them.

What I have been trying to say about human instincts and behavioural tendencies and about perception and cognition, and about our unconscious drive to prune combinatorial trees of possibilities,[136] arguably throws some light on why sharp quantum theories have tended to be ignored, even though the earliest such theory was developed by famous physicists and has been around for a good many decades.[212,215,219] I would argue that this is enough in itself to tell us, for one thing, that we must be nearer the beginning than the end[134] of science.

Scientists in public

The preceding sections try to bring into clearer view some of the psychological forces working against the public understanding of science, and against public respect for the scientific ideal. But before going further, I hope we can take stock and agree on four simple points that have already been touched on in various ways. They are hardly new, though often forgotten; and the first three at least must surely be obvious to anyone who considers them, even for a moment, regardless of specialist knowledge about the Planck scale or electrons or brain function or anything else. They must surely be obvious — glaringly obvious — to, in particular, sceptical and thoughtful non-scientists:

(i) All our knowledge of things outside us depends, directly or indirectly, on perception as well as on conscious reasoning.

(ii) Perception in the everyday sense is limited, approximate, and fallible, though astonishingly accurate and reliable in some range of circumstances (as when avoiding a highway collision, landing an aircraft, or recognizing a familiar tune or a friend's voice).

(iii) Scientific knowledge is also limited, approximate, and fallible, though astonishingly accurate and reliable in some, often much greater, range of circumstances (as when navigating to Jupiter, cloning antibodies, or building a computer that works).

(iv) Both everyday, unaided perception and the extension of it we call science depend — inescapably and fundamentally — on modelling assumptions, some of them wholly unconscious. A dependence on such assumptions is inescapable because the number of possibilities to be coped with is always combinatorially large.

The fourth point, argued for in Parts I and II, implies that what has just been said is less superficial than it might sound. On the contrary, it is about as fundamental as you can get; and it is consistent with experience. In particular, as recalled earlier, scientific advances have often depended on exposing unconscious modelling assumptions. (What looks like walking lights could, just possibly, be flying insects; it is always a matter of the balance of probabilities.)

The view summarized by the preceding four points is not, incidentally, to be confused with the 'positivist' or 'instrumentalist' view of science put forward in philosophical debates such as that on 'realism versus positivism' (*see* Part II, also Refs. 227–230 below). Those debates, like the debate on whether science is 'objective or theory laden', all seem to stem from the false dichotomy that science is either about discovering reality or about fitting models, as if you could have the one thing without the other.

Points (i) to (iv) try to summarize and reconcile what seems valid on both sides of the dichotomy. It hardly needs adding that, for given accuracy, some models are *better* than others in the sense that they seem more natural and simple, have fewer purely arbitrary elements and free parameters, have greater predictive power, and convey better or deeper insight or understanding. The 'best' models in this sense are, so to speak, more Newtonian than Ptolemaic. They satisfy, almost by definition, a strong form of Occam's razor, having properties of simplicity and beauty that help to make them accessible to our intuitions.[147–150] If such a model accurately fits some aspect of reality, then it makes that aspect comprehensible. One might say that the conscious and unconscious aspects of such models are well integrated, and mutually consistent.

Now it is easy to lose sight of point (iv), in particular, when contemplating the power, the scope, and the accuracy of hardcore scientific knowledge — the sheer *hardness* of hardcore scientific knowledge. If a model of a protein molecule composed of a hundred thousand model atoms linked in a definite way, and subject to thermal agitation in a certain temperature range, behaves as a miniature precision machine[231] or as an elaborately constructed yet reliable logic gate[174] — and in such a way as to fit data from many careful experiments — then we are impressed and awed, just as we are by cases like Fig. 3, by the goodness of fit between high precision data and the great theories, the great models, of physics, the more so when we contemplate their still more awesome simplicity, beauty, and economy[150] and their power, or potential power, to convey understanding.[147] The chance of such goodness of fit occurring by accident is combinatorially small, like the chance of opening a large combination lock at first guess.

Knowing about the huge effort that went into discovering and repeatedly checking these astonishingly accurate and reliable models, and faced with the far greater uncertainties at the research frontiers, scientists are understandably impatient, not to say angry, with suggestions — and school curriculum proposals — saying that the validity of such models is merely a matter of opinion or cultural bias.[232] To anyone who knows anything about science this is like saying that cultural bias dictates the validity of normal visual perception, in broad daylight, of a large and brightly painted juggernaut truck approaching head-on collision with your car, or that cultural bias dictates what happens when you step out of a tenth storey window. In some cases the repeated goodness of fit, and the variety of crosschecks from different viewpoints, is such that we can talk about practical certainty — about a probability still closer than unity than the probability of being dead after impact, a probability so close to unity that it is comparable, say, to the probability (and culture independence) of tomorrow's sunrise, or of green pencils not falling upward.

It is considerations like these that underlie the working scientist's shorthand terms 'proof', 'hard fact', 'decisive evidence', 'law', 'certainty', 'truth', 'true theory', 'good understanding', 'established fact', and so on. As normally used by scientists[147,224] these terms signal that attention is being directed elsewhere, away from practical certainties and near certainties, as presently judged by people who have looked at them seriously, and toward the fog of uncertainties that the scientific research is trying to penetrate. A detective trying to solve a murder mystery is not interested in lengthy discussions of whether guns thrown into rivers fall upwards or downwards, unless exceedingly good evidence for their falling upwards is unexpectedly found.

But we still have a problem, indeed a crisis. Deep in our nature, latent in genetic memory, stronger in some individuals than in others, lurks what I called the hypercredulity instinct. The word hypercredulity may be a caricature, but I hope to have convinced you that what it caricatures is something so powerful and dangerous that scientists, and democratic human societies, can no longer afford to ignore or underestimate it (as did the US State Department over Bosnia[163]). If I have not yet convinced you, then take a look at Refs. 134 and 135, or simply imagine yourself caught up in circumstances the like of which you may never have experienced, between a rising sea and a strange tribe that wants what's left of your territory and can't even speak English. Or see if you can explain in another way why human language and cognition are so strong on feelings of truth and falsehood yet so weak, as noted earlier, on logical consistency checking.

Words like 'truth' are indeed emotionally loaded, and liable to be misunderstood, by scientists as well as non-scientists, in a profoundly dangerous way. This is the case even when political temperatures are not high, even when there is no official secrecy, no deliberate camouflage and deception of any kind, no legal or commercial pressures. There have been incessant reminders of the problem. The evidence I have reviewed — including the evidence from creolization, with its implications for the nature and origins of language and cognition — shows that the problem is deep-rooted in genetic memory — more strongly, no doubt, in some individuals than others. So we are stuck with the problem, genetic engineering fantasies notwithstanding.[162]

For those of us who are professional scientists, the implication is clear. If we want to help to build respect for the scientific ideal, then we shall have to keep looking for more and better ways to remind both ourselves and the public, as many scientists do already, that claiming practical certainty (and culture independence) is different in principle from claiming, or seeming to claim, absolute, final, and infallible certainty or even the possibility of such certainty, that being awed and impressed by Fig. 3 or being convinced that a big breakthrough in theoretical physics is in prospect[150] is different in principle — profoundly, fundamentally, and crucially different — from claiming, or seeming to claim, that any scientific theory is, or could ever be known to be, exact and absolutely true with the whole universe for all time, and everything in it, as its domain of applicability.

Here, once again, things get delicate. We can reasonably, if perilously, talk about scientific truth if we somehow make clear that it means, as with pencils falling, practical but not absolute certainty.[224] We can reasonably, if perilously, talk about a search for truth, in the sense of trying to break through, of trying to make decisive advances in the scope, accuracy, simplicity, and insightfulness of our knowledge, if we somehow retain, in addition, a degree of humility: a humility that respects the complexity of things and says that we cannot expect to be infallible or omniscient — that we cannot expect science, or any other human activity, to be the absolute and certain Answer to Everything, to be the Way to an attainable and knowable absolute, final, and infallible Truth, to a knowledge of the Mind of God. To think that finite evidence can give infinite knowledge — despite the combinatorially large tree of possibilities and our unconscious drive to prune it[233] — is not only, self evidently, a cognitive illusion but arguably our most dangerous cognitive illusion. The poet Hilaire Belloc seems to have sensed this danger when he wrote, in an extraordinary sonnet first published in 1938, as the darkness spread over Europe, the lines[234]

> Believing Truth is staring at the sun
> Which but destroys the power that could perceive.

The biological, climatological, linguistic, palaeoanthropological, and perceptual–cognitive evidence says the same thing. So does the evidence from the Balkans, from Cambodia, from the Middle East, from Northern Ireland, from Rwanda and Zaire, and from Auschwitz, the obscenity of 'what men do when they aspire to the knowledge of gods.'

So I am arguing that the foregoing is the very opposite of hair splitting, and that it is relevant to scientists' professional codes of conduct and to the crises in science policy and public understanding and to the threatened crisis in democracy itself. If helping to build a stable, civilized society is among our aspirations, if we want human cultures and societies to evolve away from primitive behaviour, then those of us who are professional scientists might want to consider whether professional codes of conduct should be indifferent to a scientist's publicly claiming, or seeming to claim, that science or scientific measurements can lead us to absolute truth. We might want to consider whether to regard such claims not only as unprofessional, but more to the point recklessly irresponsible, and incalculably perilous, endangering not only science itself but also humankind — like playing with matches in an explosives factory, playing with what Carl Sagan called the 'combustible mixture of ignorance and power' now threatening to 'blow up in our faces.'[135] We might even want to consider whether professional codes should not explicitly respect a principle of humility or, if you will, 'epistemological uncertainty', acknowledging publicly what most scientists would concur with privately, that claims to the absolute, infallible, and knowably final truth of any present or future scientific theory cannot possibly — for anyone who respects the scientific ideal — have any basis beyond instinctive feeling. The same goes for simpler mantras like 'this measuring instrument cannot lie.' We might, in addition, want to remember that making such claims or seeming to do so — tempting though it may be under pressure from journalists, publishers, politicians, funding agencies, and our instinctive feelings — plays straight into the hands of those of our fellow humans who want to see scientists as just another category of warring tribes, with their own arbitrary belief systems and their tribal leaders claiming to be the mouthpiece of absolute truth. It is no accident that the conflicts thus arising are now called 'science wars'.[235,236]

So what is distinctive about science?

Have we gained any insight, then, into the 'sceptical questions asked by thoughtful and intelligent non-scientists' and into how to answer them effectively? Wearing my optimist's hat, I dare to hope that we may have. Suppose we accept, as I think most scientists do already, that both ordinary perception and science work by fitting finite, self-consistent models to finite amounts of data, and that these are indeed models and not absolute truths, even though some models are better than others, and some models simpler than others. Then we immediately have a coherent and simply explicable view of science, well supported by evidence like that described in Part II and easily understood by intelligent lay people. We can then speak accurately of 'science as an extension of ordinary perception', or 'science as our eyes and ears on an uncertain future'; and we can also — then — give clear, dispassionate, uninflated answers to the sceptical questions asked by thoughtful and intelligent non-scientists.

What, if anything, they ask, is objective and culture independent about science?

What, if anything, makes science different from other belief systems?

What, if anything, makes it different from fundamentalist religion?

Doesn't the non-uniqueness, the 'incommensurability' of scientific theories discussed by Kuhn, Feyerabend, and others show that scientific theories and beliefs are arbitrary products of culture and tribal allegiance, whose seeming objectivity is yet another illusion?

We can answer very simply. What is distinctive about science is the scientific ideal. What is distinctive, and crosscultural, about the ideal is its closeness to the deepest genetic foundations of perception — part of the genetic inheritance shared by all tribes and cultures today, an inheritance across unimaginable timespans, from many, many thousands of millennia of evolution. That inheritance provides us with the automatic, unconscious model-fitting abilities that make possible the unconscious 'science in miniature' we all develop from infancy, and use to build coherent, self consistent internal models of, and thereby become vividly aware of, the earth under our feet and the trees, mountains, ocean waves, wildlife, and people around us. These are model-fitting abilities that work approximately and imperfectly, yet whose power and efficiency, far outstripping that of any artificial intelligence system yet conceivable — solving combinatorially large problems at breathtaking speed — allow us, with remarkable consistency, reliability, and repeatability, to peel fruit, drink water, make clothes, hit tennis balls, cross the road safely, ride bicycles, fly aircraft, play musical instruments, and build ingenious and dangerous technologies.[237] The subtle, non-trivial nature of what is involved, and its limitations as well as its power, can be glimpsed by anyone who takes the trouble to notice commonplace perceptual phenomena, of which the acausality illusions described in Part II form just one rather interesting set of examples.

To questions about the non-uniqueness, incommensurability, and arbitrariness of scientific theories we can answer yes, of course, more than one model can always fit the same data, but the models are anything but arbitrary. The consistency and goodness of fit requirements are stringent, the more so when combined with Occam's razor. You can still tell the difference between a rhinoceros and Adolf Hitler. You can still tell the difference between water and alcohol, between proteins and nucleic acids, between uranium and plutonium, and between electrons, protons, neutrons, and photons. Indeed, experience shows that a good model, almost by definition, brings with it what we call 'insight' or 'understanding', as already discussed. As emphasized in Ref. 147, this is still more than the ability to tell the difference. It is related to what I called 'lucidity', involving the consistency of superficial patterns with deep patterns, the consistency between, and the tying together of, words, symbols, and pictures, the goodness of fit not only with the data but also between the conscious and unconscious parts of a model.[136]

(I have not, by the way, been trying to say that Lucidity is the Answer to Everything. Lucidity can be used for purposes quite other than getting things clear scientifically. The most powerful dictators and rabble-rousers know all about lucidity. They show very well how to make superficial patterns consistent with deep patterns when, for instance, they point to perceived enemies and scapegoats.)

To questions about the ulterior motives, not to say evil or wickedness, of scientists we must answer yes, of course, scientists have no special claim to moral purity, any more than most other people. But we can point to one thing that seems to be widely misunderstood by policymakers today, as well as by those who say that scientists' motives are wholly ulterior. Indeed it seems unfashionable to recognize, let alone value, this thing at all, despite its crucial long term importance. Part of what motivates scientists is respect for the scientific ideal, just as part of what motivates musicians is love of music. Why else would anyone undertake such labour, for no immediate reward? Indeed it is respect for the scientific ideal — not legal and bureaucratic surveillance, not financial incentives, not market forces, not even professional honours and prizes — on which successful, credible science mainly depends. It is this respect, allied with ordinary curiosity, and awe and wonder at the world around us, and the longing to understand it, that has not only led to great discoveries but has also, less glamorously but still more importantly, inspired the meticulous, laborious detective work and crosschecking, the obsessive searching for theoretical and experimental inconsistencies by many unsung, hardworking individuals, the willingness to test ideas to destruction, the willingness to take yet another look from yet another angle — in short, the huge total effort needed to produce reliable, crosscultural, crosstribal, hardcore scientific knowledge — *despite* the varying standards of personal behaviour, *despite* human lapses.[141,147,223,238–240]

Market forces, the scientific ethic, and Goodhart's law

Essential to all this hard work, and its remarkable outcome, reliable scientific knowledge, is the equally remarkable scientific ethic — the ethic of honest public and personal communication and openness of discussion, a kind of good sportsmanship, which includes the ability to get up in front of a large conference and say of your favourite theory 'I got it wrong'. Science is one of the few professions in which it is widely acknowledged, even today, that your reputation can be enhanced by publicly admitting a mistake or a refutation by experiment[304] — showing that you care more about the scientific ideal than about your own personal feelings or fortunes — and it will remain so as long as scientists, at least, respect the scientific ideal and ethic.

Such respect and its recognition and practice, despite human lapses — and despite the cultural and commercial pressures against it — are crucial to the scientific and technical ability of a nation, and to everything that goes with that ability. It is the ideal and the ethic that make high quality scientific debate possible, as distinct from the other debates in and around our legal, commercial, and political battlegrounds. It is the ideal and the ethic, and they alone, that give statements by independent scientists more credibility than statements by, or paid for by, the tobacco and other industrial lobbies. Moreover, like other kinds of idealistic attitude, the ideal and the ethic cannot be measured numerically: they cannot be audited by counting anything.

All this presents peculiarly difficult challenges to our politicians and science policymakers. One is to encourage legitimate partnerships between academic science and industry,[187] yet limit the extent to which science is compromised by the secret agendas of industry and commerce. Another, far more difficult, perhaps the most difficult challenge of all, is to create or re-create conditions that permit the scientific ideal and ethic, and independent scientific thinking, to survive, to be renewed, and to be publicly effective — despite market forces, despite legal and commercial pressures,[197,241–247] and despite human lapses.

That this last challenge is not, just now, being met is plain from the seemingly unstoppable growth of policies that encourage the lapses and discourage the ethic. Examples include the new 'counting policies', which aspire to displace peer review and long-term quality assessment by publication counting, first-author citation counting, automatic weighting by journal impact factors, and the use of other irrelevant, often short-term, numerical measures or 'performance indicators' — instead of, for instance, the 'few best publications' type of criterion long used in the most highly respected quality assessments of scientists' track records.[248]

You would not assess a bus driver by counting the number of control movements weighted by the impact factors of the controls, steering wheel 100, brakes 100, gear selector 50, and so on, instead of asking about skill in staying on the road, and trustworthiness in trying to stay on the road. In addition, you would be careful to avoid diverting the driver's eyes from the road. As my crude analogy is enough to show, the counting policies are fundamentally incoherent, especially when used to assess individual scientists. (They seem to be related to the mapping fallacies discussed in Part II.) And not only do they measure what is largely irrelevant but, still more fundamentally, they also ignore Goodhart's law that

> When a measure becomes a target, it ceases to be a good measure.[198]

Goodhart's law might be called a sociological analogue of Heisenberg's uncertainty principle. Measuring a system usually disturbs it;[149,310] and the more precise the measurement, and the shorter its timescale, the greater the energy of the disturbance. Moreover, the disturbance has unpredictable results in most cases. This is, or should be, mind-blowing to anyone who believes that Everything Must Be Measured as precisely as possible, and that the results must be tightly linked to, say, people's salaries. The likely outcome is chaotic dynamics,[186] a far cry from the intended Continual Improvement and Enhancement. Charles Goodhart, incidentally, was an economic adviser to the Bank of England. According to the 99th edition of Pears Cyclopaedia (1990–1, pp. G 27, G 31) — see also the extended discussion by Hoskin[198] — the original form of Goodhart's law states that 'as soon as the government attempts to regulate any particular set of financial assets, these become unreliable as indicators of economic trends'. This is because 'financial institutions can... easily devise new types of financial assets.' In just the same way, bus drivers can invent new styles of bus driving and bus-driver training; and they will, of course, do so if feeding their families is made to depend on it.

On top of all this, adding to the chaos, there is the mismatch of political and research timescales: the imposition of sudden changes in research funding priorities, as if scientific research were a kind of sausage machine or production line, or a tap that can be turned on and off at whim.[249] There is the growing pressure to become wholly reliant on funding from industry — misconceived as replacing public funding[197,245,246] and already a potent threat to scientific independence and credibility.[244,249,250] Thus cancer research is to be sponsored mainly by the tobacco industry, ecology and food safety by the food and pesticide industries, and environment by the fossil fuel industry. There is the growing pressure to commercialize all scientific data as someone's 'intellectual property',[251] delaying independent research or stopping it altogether — and endangering still further that endangered species of scientists who build good public databases, an activity essential to today's science and seldom adequately recognized.[251a].

Indeed, there has been increasing pressure to introduce legal and political confrontation, and financial incentives, directly into scientific debate.[242,247] Personal harassment and character assassination have also been used, in at least one case I know of. The case is well known in the atmospheric science community I work in.[241,247] As soon as everything is governed by legal and financial pressures, by the power of unconstrained market forces — by the belief (which brooks no questioning) that More Competition is Always Better — the scientific ideal and ethic will have little chance of surviving on the relatively slender resources available to them.

These by the way are not complaints. They are just comments, and food for thought, relevant to the issues of scientific independence and credibility, and to whether human societies wish such independence and credibility to survive or not. I dare to suggest that these are the most fundamental issues for the public understanding of science. Perhaps they are even, in the long run, the most fundamental issues for humanity. Do human societies wish to have independent thinkers who really know about genes, viruses, reliable computer systems, smart materials, quantum cryptography and code-cracking, climate change, future sea levels, the chaotic dynamics of earth–asteroid collisions, and so on — and who are willing to work hard to make the essence of that knowledge publicly available, and to be honest about degrees of uncertainty — or not? Would human societies prefer that most such knowledge should become a commercial or political secret, following today's trends? Will human societies understand that the smartest people who know the most about these things are being given huge incentives to switch to other, and far more lucrative, ways of earning their living?

History clearly shows that it takes years of hard work by many individuals to do anything significant and credible in science, and that secrecy, corner cutting, cutthroat competition, and interference by vested interests must, inevitably, multiply mistakes and delay correction, even when they do not lead to total confusion. Careful experimentation, conscious model-fitting, looking for unsuspected possibilities, meticulous crosschecking — taking yet another look from yet another angle, letting others check what you are doing — are slow and arduous processes.[223] And they depend on cooperation as well as competition. Anyone who believes that More Competition is Always Better ignores the crucial role of cooperation between scientific colleagues. Such cooperation explains why there are, against the odds, such things as the scientific ethic and the implied tradition of openness.[304,304a]

How that very surprising tradition arose against the odds — against the normal urge to be secretive about specialist knowledge — is an interesting story in itself. The tradition appears to have resulted from particular circumstances in Renaissance Europe, in which wealthy aristocratic establishments found themselves competing for what we now call scientific prestige and credibility. For the first time in history, there arose pressures for peer review and open publication. The by-product was a sequence of astonishing and spectacular scientific advances, despite human lapses, as brilliant minds were enabled to build on each others' work, at an unprecedented rate. This point is carefully made in the last reference of 304. Nothing succeeds like success. Surely this was memetic evolution at its most spectacular, and comparable, perhaps, to the cultural sea change that must have produced — if you agree with geneticists that genetic evolution could not have been fast enough — the sudden acceptance of, and flowering of, the recorded visual arts, against the odds,[286] in the Upper Palaeolithic.

Today there is no real doubt that cooperation maintained *against* competitive pressures is a practical necessity for sustainable scientific development, for keeping our eyes and ears open to an uncertain future, for keeping our heads out of the sand, and indeed for the long term development of sustainable commerce and industry.[252,256,303] Whether we like it or not, the scientific and engineering problems that confront us today are vastly too difficult to be solved by individuals or small groups working in isolation, no matter how talented. The lone genius who solves everything singlehanded, though commonplace in science fiction, does not exist in the real world. Real geniuses like Richard Feynman have said as much.[311] Harsh experience makes the point again and again.

A particularly clear, cogent and timely demonstration of the point has been the creation of the complex yet reliable general-purpose computer systems known as GNU/Linux and the Internet.[304a] This very remarkable achievement was made possible by the flowering of what is variously called the 'open source' or 'free' software community, whose ideal and ethic are essentially those I have been discussing — what I have been calling the scientific ideal and ethic. In some ways this was another Renaissance, a fresh rediscovery of the enormous power of cooperation.[304a]

All this says that the scientific ethic, and the need for cooperation as well as competition, could hardly be more basic to any society that wishes to be scientifically competent, or even to develop such practical necessities as reliable banking and other computerized infrastructures. This comes close, dare I say it, to being a truth in the scientist's shorthand sense, a practical certainty about the way science works and about the way it achieves credibility, a practical certainty argued for by long, harsh experience of problem-solving against the odds. A challenge for the millennium will be to find increasingly effective, and non-hypercredulous, ways of speaking truth, in this sense, to power, as some courageous scientists and policymakers have always tried to do. For the signs are that science today, still more the science to be practised tomorrow by the next generation, by today's science students, is being deeply damaged by too much secrecy, too much competition, too little cooperation, too much pressure to cut corners, too little independence, and — as shown by the bus driver analogy — entirely the wrong kind of auditing. These are among the incentives I am talking about — the incentives for individuals to abandon science in favour of something more lucrative and perhaps, today, more satisfying.

Let us not put too fine a point on this. There is already too much pressure on scientists to succumb to Goodhart's law, to play games to maximize short-term performance indicators instead of doing good science[198,200,248] — to replace 'few best' by 'many worst', to maximize noise to signal in the scientific literature, to wear out the brakes and steering gear and dizzy the passengers. Worse still, there is too much pressure to do and say, in the end, what the market will pay you to do and say.[197,244,247,253] The same pressures threaten, for instance, independent journalism, an essential ally if public understanding is to be built: one of our most respected journalists, Martin Bell, recently felt moved to remind us, on the record,[253] that '... if ... nothing matters but money ... then in that case news is only what you say it is'. For 'news' you can, of course, read anything at all, including 'science' and 'scientific truth'. Ref. 247 gives detailed examples. And science policymaking is pushing ever harder in these same directions — partly unconsciously, it seems, and partly consciously and against its own better judgment.

What could be behind such astonishing shortsightedness? It seems plausible that the power driving it all is the power of market-force hypercredulity and the associated belief systems. These seem to include, first, the unquestioned belief that Business Methods are Always Best — as if there were a single, coherent body of such methods, and as if real businesses do what they say they do, and as if they now do what they used to do — and, second, the unquestioned belief that Everything Must Be Measured (in dollars if possible, or failing that in some other numerical measure of 'quality', 'value', 'output', 'productivity', 'performance', etc.), leading to, or reinforcing, today's audit culture and the replacement of trust, responsibility, and professional ethics and sanctions by a new kind of 'accountability'.[197–200]

'Accountability' is a word having great numinous force, but, within today's audit culture, a changed meaning, or, rather, no coherent meaning. For 'accountability', as the word often seems to be used nowadays — perhaps the word should be 'neoaccountability' or 'pseudoaccountability' — has become a self-contradictory term, like 'heteroactive barber'.[136,198] It is a negation of, as well as a conflation with, the older meaning of responsibility to some authority. It takes for granted — ahead of conscious thought — that trust, responsibility, professional ethics, and the usual checks and balances are to be treated as having zero value, not so much because they fail now and then, but above all because they cannot be measured. They are to be recognized, therefore, through lip service only, and given zero or negative incentive. In principle, and 'in fairness', it says — or unconsciously assumes, without ever saying so — that *no* individual can be trusted to act responsibly without continual pressure from a body of auditors. Notice the incoherence, the straightforward inconsistency. Actual adherence to the belief, in the sense of putting it into practice, would be impossible in a non-totalitarian society. Actual adherence would imply an infinite regression, and an infinite cost, the auditing of the auditors of the auditors and so on.

Other conflations and inconsistencies include the use of the phrase 'public accountability' to mean compliance with the wishes of private commerce, or, what is nearly the same thing, compliance with whatever is, or seems to be, dictated by market forces. The conflation of 'public' with 'private' — Ref. 197 provides a clear example of this conflation — well illustrates the power of the hypercredulity instinct to divert attention from even the plainest and simplest logic.

I can hardly do justice to the sublety, pervasiveness, and gridlocking potential of the audit culture. For instance it purports to escape the infinite regression of the auditing of the auditors, and to cut costs, by espousing Adam Smith's dictum of self-auditing. But the incoherence remains. The infinite regression is inescapable. Smith, also one of the great prophets of market-force hypercredulity,[245] tells us to split ourselves into two persons, the auditor and the audited.[198] But that naturally requires another split, because of the self-evident need for another self to audit the self-auditor. For why should the self-auditor be any more trustworthy than the self being audited? This in turn requires another split, then another, and another... . What then shall we call it? 'Hyperschizophrenia' is not quite right. Mathematicians and computer scientists have 'divergent sequences' or 'blowup'. Physicists have, or used to have, the electron-spiral catastrophe. Perhaps we should speak of paralysis by the 'self-audit catastrophe'.

Speaking in defence of the scientific ideal and ethic, speaking in defence of the meaningful appraisal of scientific research[248] and of restoring coherent meaning to phrases like 'public accountability' ' *Nature*, 1998, **395**, 727 — speaking truth to the power I am talking about, the power of market-force hypercredulity and the associated belief systems — will continue to take courage as well as skill. It will mean daring to say, again and again, that for sustainable democracy, for government by consent — for a society wishing to avoid the descent toward raw tribalism or totalitarian brutality — to say, again and again, that the scientific ideal and ethic are not luxuries but necessities. It will mean daring to say that trust, responsibility, and professional ethics need to be recognized as valuable even though they cannot be measured[254] — that they need to be recognized, by some means or other, as *incalculably* valuable. It will mean daring to return to the idea of consciously limited auditing, to the idea of checks and balances, with sanctions where necessary, that encourage personal responsibility and are not combinatorially large — that recognize the need for independent scrutiny but also acknowledge, openly, that Everything *can't* be measured, if only because Everything is combinatorially large.

It will mean daring to say, also, that science dominated by unregulated market forces, by monetary profit alone — as advocated in the politically influential book by Adam Smith's disciple, Terence Kealey[245] — will be tobacco company, food industry, or fossil fuel science[247] and not open, credible science. (That such a thing should need saying at all is significant in itself.) It will mean daring to say that suppressing open, credible science will be like shutting your eyes to oncoming traffic in fog, daring to say that if you think keeping your eyes open is expensive then you have not even begun to see the cost of shutting them — not only the cost of squandering human and natural resources, but also the cost of deepening the confusion and ignorance in human societies and the cost, also incalculable, of encouraging primitive behaviour patterns. It will mean daring to point out — oh sacrilege! — that market-force hypercredulity and market forces gone wild are the ultimate in unaccountability, in its old sense, meaning straightforward, reckless irresponsibility, on a global scale, on a scale that could easily devastate the Earth's life support system.

It is strange indeed, and significant, that this is so seldom pointed out. [*Note added April 1999:* This is already changing, speeded by the Asian financial crisis, the debates on the 'Third Way' — a determined attempt to escape dichotomization — and such contributions as George Soros' recent book *The Crisis of Global Capitalism*, etc. I shall have to do some rewriting around here, though I suspect that market-force hypercredulity will remain powerful for some time.] ....

As already mentioned, we are told that we must be 'publicly' accountable when what is meant, quite often, is accountability to market forces.[197] Yet market forces, as such, are accountable to no one, in any sense of the word accountable.[155] Market forces have chaotic dynamics[186] and vast destructive power — as experts as well as actual events have been reminding us recently[319] — yet to dare to question their absolute dominance, their total autonomy, still seems to be taboo in many still-influential circles.[255] Market forces are not, in themselves, virtuous and sweetly reasonable as Kealey's book[245] tries to persuade us. Left to themselves — 'deregulated', as it is called — market forces are indifferent to real costs, such as the cost of sea level rise, which cannot be discerned on the timescale of the quarterly financial report.[244] They have less to do with virtue and sweet reason than with adrenalin, warmaking, and gambling. They feed on the urge to annihilate the competition before it annihilates you[155] and on the urge to tickle the monster's tail,[166,189] to risk all for the killing. Market forces left to themselves produce the 'winner take all' culture and the human scrap heap, the seedbed of social instability, the hothouse of criminality, the recruiting ground for enterprises like the kidnapping industry. Market forces know no limits to gambling, not only gambling with stocks and shares, with people's currencies and livelihoods all the way to financial meltdown — but also gambling with our food sources, with our children's education, with our physical and mental health, with the accelerated evolution of viruses, bacteria, and other disease agents, with sea level, rainfall, and air chemistry, with human population growth and mass migration, and, above all, gambling with our most powerful, dangerous, and destructive instincts, with the dark side of the Platonic, with the risk, the perfectly real risk, of unstoppable terrorism, ungovernability, and social catastrophe on top of environmental catastrophe. As it is written, you can't buck the market; but the market is not so much a pagan deity, a devouring monster,[166] as a global-scale nuclear reactor: as is now increasingly recognized, it could self destruct in any of several ways, whether or not the sea level starts to rise significantly.

It is very likely, by the way, that if the sea level were to start rising at a rate that is clearly detectable, and clearly attributable to greenhouse-gas buildup, then, at that stage, it would be too late to stop it by reducing greenhouse-gas emissions, even to zero. Over the following century or so, there would be, at any given time, an underlying *rate* of 'sea-level inflation', the contribution due to thermal expansion, related to the *amounts* of long lived greenhouse gases that had accumulated in the atmosphere by then. What is far more uncertain is just how much greenhouse-gas accumulation is required to produce a given underlying inflation rate,[256,257] and how much difference other factors might make: see the *Corrigendum*[400] to the published version of this discussion.

I am not denying the great usefulness of market forces, nor their important evolutionary significance for today's world. I am merely suggesting that hypercredulity is involved, and that this has implications for, among other things, science policymaking — that it poses a grave threat not only to social stability at large, but also to the integrity, to the independence and credibility, of science as our collective eyes and ears on the future.[312] To anyone who doubts the reality of that threat, I would point first to the popularity of Terence Kealey's ideas with influential journalists, politicians, and others, as evidenced through newspaper commentaries and through the presentation to him several years ago, by the UK Prime Minister, of a prestigious 'Aims of Industry' award. Second, I would point to what Paul A. Davies has described as the 'flawed economic logic' in Kealey's book,[245] and 'the telling of stories that blatantly disregard the evidence'.[302] David, a respected economist and economic historian, backs this up with an extended, detailed discussion. Third, I would point, perhaps most revealingly, to the book's explicit claim that Market Forces are the Answer to Everything: for instance, on p. 344, '*Laissez faire* meets all [*sic*] needs'.

Defence of the scientific ideal and ethic, then, and renewal of the mandate to keep our eyes and ears open will require not only courage, as it has always done, including the speaking of truth to power, but also — to make such speaking credible — the avoidance of hypercredulous attitudes on our own part, as scientists, requiring in turn the most scrupulous honesty, a greater honesty than in the past, about the limitations of science and the limitations of technogical fixes.[237,255] Scientists in the public eye can help by being quick to acknowledge those limitations, and to show respect, and to urge respect, for scientific uncertainty and for the formidable difficulties, for the sheer labour, involved in reducing that uncertainty, in coping with the combinatorially large tree of possibilities. We are finite creatures, fitting finite models to finite amounts of data, and there will always be problems whose complexity is too great for us. Science at its best has the strongest possible claims to objectivity; but there never has been, there never can be, and there never will be, absolute certainty. Contrary to popular opinion, this is something that many scientists, probably the vast majority, have always recognized,[287,312] if only because a claim to absolute certainty is in itself a clear rejection of the scientific ideal.

And, practically speaking, even for the most flexible and best trained minds, there will always be mental tunnels, cognitive illusions,[140,188] and false dichotomies, from the inappropriate pruning of the combinatorial tree — from the premature fall of Occam's razor. Such phenomena are inescapable consequences of the way perception and cognition work.[233]

I think that familiarity with a few cognitive–perceptual phenomena should become part of the education of schoolchildren.[151] Not only do such phenomena underlie whatever we do and think, but they are also, as I have tried to argue, fundamental to understanding what science is. They are also part of the danger of quick technological fixes,[237,255] part of what underlies the instability, the chaotic dynamics, the boom and bust of markets, and part of what underlies the conflations and distortions of 'fact', 'opinion', and 'consensus' that bedevil political and legal debates about science and scientific uncertainty. They are part of why scientific debate must, somehow, be kept separate from legal and political debate, and the distinction between the two more widely appreciated. They are part of why 'science and politics don't mix', even though they must increasingly live together.[305]

And surely, as another practical certainty, there will always be problems wholly outside the scope of science. Surely scientists must be quick to admit this too. What happens to my subjective sense of time when I die? Is it finite, infinite, indefinite? Contrary to what some scientists seem to claim, science has nothing to say about this. Some questions about subjective time can be studied experimentally but this, quite clearly, is not one of them. For the present at least, and arguably for the foreseeable future, it is a matter of personal faith, and personal faith alone.[259] It seems to me that we do a terrible thing when we needlessly and groundlessly — without a shred of evidence — deny individuals facing death the resources of personal faith they might need.

It is worth reminding ourselves, incidentally, that some uncertainty need not be a bad thing. In a lucid, technically accurate, and perceptive 1-page article in *Newsweek*, 8 December 1997, Oliver Morton put this very well.[315] He discussed the science and politics of global environmental change, deftly summarizing what we know and what we do not know, and aptly emphasizing the uncertainties. The article points out that a modicum of uncertainty in this area could be a great blessing in disguise. For, in the unlikely event that we were to attain absolute or even practical certainty about how climate, air chemistry and sea level would change in response to pollution, the immediate consequence would be a terrible conflict between the world's countries, as it became clear who would be winners and losers in different pollution scenarios. Conversely, Morton points out, 'The veil of ignorance that makes it harder for countries to know where their best interests lie may mean that they are more easily led to look for the common good.' The result could yet be exciting new technologies, thriving new industries, and cleaner air to breathe.

Postlude: An Optimist's Millennium

I want to say something about the grass-roots social experiment called the Grameen Bank of Bangladesh, whose remarkable success is beginning to be known outside specialist circles.[314] The Grameen Bank has existed since 1983 and has shown itself to be a powerful catalyst of cultural change and social stabilization. It has pioneered the practice of 'micro-lending' to impoverished rural people. As a lending bank, with many of the same impoverished rural people as its shareholders — and with no subsidies whatever — it has confounded cynics with a bad-debt rate less than half a percent. The typical loan size is of the order of $100, and the rapidly growing turnover is already in the hundreds of millions of US dollars at the time of writing (1998). The bank is showing how the intelligent and principled use of market forces and of information technology is not only capable of alleviating poverty as such — through the honesty and hard work of people released from the stranglehold of local moneylenders and information-controllers — but also capable of doing so in a socially beneficial way. The results include the building of self-esteem and spiritual health, the emancipation of women and the stemming of population growth, and the reduction of pressures to migrate to cities and to richer countries.

Scientists cannot take any credit for this. But science can. The emancipation of women has been facilitated by the scientific understanding of physiology and biochemistry, allowing all children to be wanted children. Such emancipation also depends on the breaking of prejudice, the loosening of thinking, the escape from hypercredulity that would be difficult to conceive of, as I have argued, without a cultural background that respects the scientific ideal or something like it, which means that it repudiates the 'wilful and determined ignorance' of ordinary conviction politics.[247,313] And the cheap information technology that is now amplifying and diversifying the effectiveness of micro-lending would have been inconceivable without that astonishing, though imperfect, intellectual edifice we call quantum mechanics.

I must return briefly to the issue of scientists' professional codes of conduct. The way scientists behave might be enough to tip the balance, one way or the other. Fairly or unfairly, scientists — even if not holding forth about life after death — tend to be perceived as arrogant and inhumanely cold hearted. But here, too, one can be optimistic. It is not beyond imagination that such perceptions might change. Indeed, by publicly showing respect for the scientific ideal and ethic, and the humility this implies — and once again I mean humility, not apology[136] — scientists can not only help credible science to survive but can also make, and are making, a humanitarian contribution that will be important in tomorrow's dangerous world, a contribution toward our children's chances of a civilized future. When, in 1930, in front of the newsreel cameras, a journalist asked the Mahatma Gandhi what he thought of modern civilization, the Mahatma replied, 'That would be a good idea.'[255] The optimist in me hopes you agree.

A civilized future would entail not just a 'new social contract' for science at the level of politics, economics, and auditing[260,261] but also a new understanding, a new commitment, a new *covenant* between science and society, reaching all the way back to the education of schoolchildren. 'Covenant' literally means a coming together: a meeting of minds, an understanding in both senses of the word — that is, insight on the one hand and agreement, on points of principle, on the other. Such a covenant would have room for personal dignity and personal faith alongside a deeper understanding of what science is and of where it came from, and of where we came from. It would repudiate the claim that science as a personal faith disproves all other personal faiths,[262] and it would aim to defuse tribal conflicts like the current 'science wars'.[235] Such a covenant would find ways of valuing, as indispensable, the professional ideals and ethics discounted by today's audit culture — inadvertently perhaps, but discounted all the same. The building of such a covenant might involve the mass newsmedia in surprising and unprecedented ways (Note 263, point (iv)). It might receive unexpected support, in unexpected ways, from grass-roots movements like the Grameen Bank and other new bottom-up agents of cultural, social, and spiritual change.

I have argued that such a covenant will scarcely be possible unless those of us who are scientists are seen to respect the scientific ideal. And I have argued that such respect demands that we explicitly renounce, as many already do, as a matter of professional principle, any hint of claims to humanly knowable absolute truth or final certainty or to the possibility of such certainty.

If we feel the urge to make such a claim — whether it concerns quantum principles, genetics, hyperintelligent computers, future sea levels, or any other scientific question — we might ask ourselves whether such an urge might not be instinctive, primitive, and profoundly irrational: in a word, hypercredulous. We might in any case ask whether we ourselves as professional scientists, however firmly we are convinced of something, should risk looking just like ordinary fanatics and zealots, or arrogant triumphalists, and whether zealotry should not become a matter for consenting adults in private. We could remind ourselves of all the past occasions when absolute certainty was announced by scientists and later retracted or discredited.[264] We could ask ourselves whether we are careful enough about words like 'true' and 'truth', when we want to use them or are pressed to use them. We might consider whether tribal language like 'scientific heresy' should be used at all, by professional scientists. We might consider whether to cultivate, still more fully than hitherto, and as a recognized part of professional practice and professional etiquette, ways of speaking and writing that manage to stay simple yet firmly emphasize the balance of probabilities — recognizing the overwhelmingly probable, as with the oncoming truck or the timescale for sea-level inflation,[258,295] but not confusing it with the absolutely certain.

We might ask — and please consider whether to call this sacrilege or sanity — whether it should not be a point of professional principle to regard the tacit distinction between 'true theories' and 'mere models' as yet another false dichotomy, while acknowledging that some models are, of course, far better than others: that is, acknowledging the overwhelming superiority and insightfulness of some models over others, their awesome success so far, as illustrated in Fig. 3 and in many other ways, and acknowledging the possibility of still greater success.[147,150,211,212,265] We might consider whether such professional practices and principles, including the humility principle, if publicly declared, could help to reverse 'the declining social authority of science'[266] or, better still, help to increase, not respect for authority as such, but respect for the scientific ideal and ethic. We might consider whether such practices and principles could help scientists in the public eye to resist, for example, the dangerous pressure to conflate scientific problems such as understanding medical or environmental hazard, which demand openmindedness, with ethical, legal, and political problems such as managing medical or environmental risk, which demand decisionmaking,.[241–252,257,267–270]

Admitting our limitations, recognizing that human abilities are finite, understanding that 'perceived reality' and 'observed fact' depend on unconscious model-fitting and that science depends on a more conscious kind of model-fitting need not, surely, undermine human dignity and self respect.[129] It need not diminish the richness of our experience of ourselves and the world, nor the mystery of it. Such understanding, and scientific understanding in general, must surely increase, not decrease, our awe and wonder at the nature of things, at the miracle of knowing as much as we do know, and at the promise of yet deeper knowing and understanding. Knowing that poetry and music can be found in acoustic time series, and in binary numbers etched into an optical disc, must surely enhance, not diminish, their power to move us. Children, more than adults, ask the key question, 'Mummy, how did they get a whole orchestra into that thin little disc?' Knowing that science and the arts both have a deep biological significance, that they have to do with genes and our ancestors' survival, with juvenile play and with education that works, and with the marvellous and multifarious developments that we call culture — knowing that nature and nurture intimately and subtly work together, that nurture is part of nature, in infancy and beyond — surely all this should enrich, not impoverish, human life. Admitting that the known laws of physics are only approximate, though exquisitely accurate, and that they point to deeper mysteries not yet fathomed, must surely increase, not decrease, our sense of the grandeur of the universe.

We are indeed a highly adaptable species. What we call the Third Millennium may, with luck, become approximately the eleventh millennium of the Earth's stable climate. Perhaps, against all the odds as they seem at present, the scientific ideal and ethic will survive and strengthen. Perhaps there will, indeed, be some kind of new covenant between science and society. Perhaps the ideal and the ethic will help us to meet the threats we face, including the threat from today's psychological nuclear energy, market forces run wild. Perhaps we shall yet learn to harness that energy nondestructively, to change the primitive, warmaking cultures of hypercompetition, of hypergambling, of 'winner take all' and evolve sustainable, stablilized market economies, in which the competition is fairer[155,156,271,247,255,281] and which can evolve by organic cultural change without blinding us to the future. The current 'third way' debates promise this already. As Bernard Levin once wrote,[272]

> In every age of transition men are never so firmly bound to one way of life as when they are about to abandon it, so that fanaticism and intolerance reach their most intense forms just before tolerance and mutual acceptance come to be the natural order of things.

Perhaps an optimist at the dawn of the Millennium could dare, then, to dream even of new ways of personal belief, and spiritual health, that respect both the scientific ideal and human experience, including artistic, mystical, and visionary experience, without claiming to have the answer to everything. Perhaps an optimist, inspired by examples like the Grameen Bank, could dare to hope that the trauma of supranationalization, or so called globalization — economic, informational, and disinformational — will at least favour organic cultural change over social catastrophe[256,263,303,309] and help us find these new ways.[154–156,203] Perhaps there will emerge in the end, against the odds, a wiser use of our instinctive powers, scientific, artistic, and emotional — a wiser use that transcends what I called the hypercredulity instinct, keeping the power to be enthusiastic, to be inspired, to hope, to be loyal to those we care about, to be constructively tribal or constructively national,[172,273,318] to cherish and respect personal truths and to 'rediscover the sacred' in new ways, to be courageous, to dare acts of faith, yet freeing humankind from the need to play God. Perhaps we shall dare to understand, even better than today — and dare to accept — the nature and origins of our own instinctive powers. Perhaps we shall dare to know our shadow and our light.

Acknowledgments

The point made in Part II about Theories of Everything, that Gödel's theorem precludes them, has previously been made by John Barrow.[274] I am grateful to the following people, as well as to the people and organizations listed in the Acknowledgements of Parts I and II, for helpful information and comments: Leslie Aiello, Ross Anderson, Paul David, George Efstathiou, Jonathan Gregory, Geoff Jenkins, Chris Jordan, Judy Kegl, Malcolm Longair, Albert Libchaber, Trevor McDougall, Rose Mitchell, Walter Munk, Sandu Popescu, Jacques Prost, Sarah Raper, Marilyn Strathern, Daphne Sulston, John Sulston, Lonnie Thompson, Scott Tremaine, Jonathan Sahananda Wolfers, Peter Wolfers, and Carl Wunsch. Antony Pay again gave especially valuable help and encouragement. Mark Hull in the *ISR* office lent great editorial skill and took meticulous care, far beyond the call of duty, in seeing this rather massive three-part series through the press.

Notes and literature cited

The numbering continues from that in Part II.

128. The late Michael Tippett wrote these words, and set them to music of great simplicity, power, and beauty, during the dark years around the beginning of the Second World War. The words and the music express a vision of hope that is still needed today, and is the theme of this article. *See* pp. 136–149 of M. Tippett: 'A Child of Our Time: oratorio for soli, chorus and orchestra'; 1944, London, Schott, 157 pp.

129. J. Maddox: 'The prevalent distrust of science', *Nature*, 1995, **378**, 435–437. Maddox tells of a distinguished architect who said at dinner 'I suppose you must be one of those frightful Darwinists', representing the feeling that scientific understanding 'could only undermine people's sense of their own dignity and self respect, and sap their will to aspire to better things.' To many thoughtful and intelligent people it seems that scientific 'understanding' is equated with such things as brutal biological determinism and eugenic madness,[130,162] with metaphors like the 'clockwork universe' and the 'selfish gene' taken far too literally — all associated with the idea that we ourselves are machinelike in a naive, simplistic, and absurd sense, that we are machines only a few orders of magnitude more complicated than the machines we ourselves make, and therefore qualitatively similar. This is a mistake sometimes made even by professional scientists; it may come from forgetting the smallness of molecules, the unimaginable largeness of combinatorially large numbers, and the *qualitative* consequences of hypermassive parallelism — the so called 'emergent properties' of unimaginably complex systems.[161,168–171,204,205] My personal and, I believe, strong reply to the architect's concerns is given in the present article, in the sections labelled 'Respect and humility' and 'An optimist's millennium'. Science does not say that we are simple machines; and I argue that it gives us more reason than ever 'to aspire to better things'.

130. A potent symbol of our fears and imaginings is, of course, the ever persistent image of the mad scientist, the singlehanded creator of horrific new weapons and cyborg monsters.[275] The image of the mad scientist and the fears it represents — among other fears[134] — are arguably, for reasons to be explained, a far greater threat to human societies than any threat from real mad scientists, who are unlikely to be respected as scientists hence unlikely to be given access to dangerous laboratory materials and equipment. As Richard Feynman once remarked, even a lone genius cannot singlehandedly solve problems near the research frontiers without the interest and cooperation of co-workers or colleagues, to say nothing of expensive equipment — whereas ordinary firearms, incendiary materials, and explosives are readily obtainable by mad scientists and mad non-scientists alike. It is frightening, of course, to hear a self proclaimed scientist going public with reckless talk, as with the individual who recently announced an intention to carry out human cloning in the near future, professing a belief that 'cloning and the reprogramming of DNA are the first serious steps in becoming one with God' (also *Science*, 1998, **279**, 315, *Nature*, 1998, **391**, 211 and 218–219, and many newspaper reports around mid-January 1998). The announcement seemed to show no awareness of the possible psychosocial consequences of such a thing, nor of safety considerations, as indicated by the low success rate, 1 in 400, with sheep, nor of the other huge uncertainties in the early days of a one-off experimental success (e.g. *Science*, 1998, **279**, 635–636, & refs. therein). Professional scientists were quick to distance themselves from the individual concerned. **Update:** Professional scientists are having to continue to distance themselves from individuals who ignorantly[162] talk of 'DNA programming' and 'genome sculpting'. To my knowledge, no recognized scientist working in the field indulges in such talk. Recognized scientists and other serious participants in genetic engineering research tend to talk, rather, about supporting and informing serious debates on the ethical issues, as the techniques develop apace — as illustrated by the subsequent cloning of several mice reported in the 23 July 1998 issue of *Nature*, both in a news item (**394**, 315–316) and in a research paper by T. Wakayama, A. C. F. Perry, M. Zuccotti, K. R. Johnson, and R. Yanagimachi: 'Full-term development of mice from enucleated oocytes injected with cumulus cell nuclei', *Nature*, 1998, **394**, 369–374. See also the news item in *Science*, 1998, **281**, 495–496.

131. M. Potts: 'Unmet demand for family planning', *Interdisc. Sci. Rev.* , 1993, **18**(2), 103–111. Gives hard evidence for the unmet demand, and 'the remarkable fact ... that fertility has fallen in a number of developing countries two to four times as rapidly as it did in the West at a comparable stage of the demographic transition'. *See* also M. Perutz: 'The fifth freedom', *Europ. Rev.*, 1993, **1**, 243–248, and K. Hagenfeldt: 'Current status of contraceptive research and development', in 'Population — the complex reality: a report of the population summit of the world's scientific academies' (ed. F. Graham-Smith), 1994, 271–285, London, Royal Society/Golden, CO, Fulcrum, North American Press, 404 pp. For later reference,[196] note the evidence in this last paper that population control is a case in which market forces and legal pressures have had a clear negative effect. During the period 1965–74 of a review sponsored by the Ford Foundation, for instance, support by the pharmaceutical industry for research on improved

contraception methods was 'cut by more than half', from 34 to 16% of the total support, 'apparently as a result of the revised assessments of the potential profitability of new contraceptive methods'. On the other hand, market forces used in very different way, by the indigenous organizations known as Grameen Banks, are part of the reason why fertility in developing countries has been falling.[314]

But *see*

132. J. Davies: 'Bacteria on the rampage', *Nature*, 1996, **383**, 219–220. Also cited as Ref. 74 of Part II, this is one of a continuing stream of reports on MRSA (methicillin-resistant *Staphylococcus aureus*) and other emerging 'superbugs' showing resistance to increasing numbers of antibiotics; for a more recent commentary, *see* Ref. 276. Such resistance, now spreading both inside and outside hospitals — a natural result of the profligate use of antibiotics — can be passed from one bacterium to another in genetic packages called plasmids consisting of loops of DNA. [I should not, incidentally, have spoken of plasmids, as such, as 'model fitters' in the Part II version of this Note; rather, it is the whole ensemble of vast numbers of bacteria and plasmids that could be said to do model-fitting, i.e. to behave, collectively, somewhat like mammalian immune systems — with the variability and versatility to adapt to environmental pressures from antibiotics or from anything else (J. E. Sulston, personal communication).] There is now, furthermore, good evidence that the evolution of bacterial populations is not the only kind of evolutionary adaptation giving rise to new or more intractable disease agents; *see* for instance Refs. 138 and 139.

133. It hardly needs saying that the increasing numbers of options for meeting such threats, including the threats from new diseases, depend crucially on scientific skill and knowledge. Kauffman's book[204] is a excellent reminder of just how numerous, and how surprising, some of those options are becoming. Arguably important, too, are the unprecedented opportunities for organic, non-catastrophic cultural change, now that global scale information technology is beginning to emerge from its infancy while developing — for powerful economic reasons — a degree of robustness against partisan control and censorship.[154]

134. J. Horgan: 'The end of science', 1996; London, Little Brown, 324 pp. This contribution to the age-old 'Götterdämmerung genre' — the insistence on the imminent end of things that forgets about such things as adaptability and combinatorial largeness — is permeated by what the author himself calls 'metaphysical anxiety'. This is an anxiety or disquiet that I take to be of the kind discussed in Ref. 174, and whose likely origins I shall further discuss here. The author associates it with a personal experience, a visionary experience of cosmic ecstasy then despair, described in an epilogue entitled 'The terror of God'. He shows a strange mixure of scepticism about, and obsession with, the powerful and dangerous myth that science is a quest for absolute or ultimate truth. The book is of interest for its collection of interviews with some of the world's most prominent scientists. It illustrates in countless ways what I mean by today's 'widespread, profound, and dangerous confusion' about science, and the undermining of respect for the scientific ideal.

135. C. Sagan: 'The demon-haunted world: science as a candle in the dark'; 1996, London, Hodder Headline/Random House, 436 pp. This important book by the late Carl Sagan, a respected scientist and popularizer of science,[206] documents, in some detail, just how 'widespread, profound, and dangerous' is the current confusion about science, and how it is being worsened by the market driven dissemination of pseudoscience: 'Demons sell; hoaxers are boring and in bad taste' (p. 76, end of Chap. 4, about the crop circle hoax and the public testimony of the hoaxers). Not all busy scientists and science policymakers seem to have appreciated the full significance of this confusion, whose origins, reasons for growth, and implications for democracy I try to expose here. Among many important features of Sagan's book is its incorporation and expansion of material that first appeared in *Parade* magazine, together with extensive and eye opening verbatim reactions to it from members of the public. As he aptly puts it on p. 28, after mentioning our dependence on science and technology, 'We have also arranged things so that almost no one understands science and technology. This is a prescription for disaster. We might get away with it for a while, but sooner or later this combustible mixture of ignorance and power is going to blow up in our faces.' *See* also the discussion in Chap. 3 of Ref. 247 of the rise to political power of 'a most wilful and determined ignorance', and the allusion, at the end of Ref. 261, to a Calvin and Hobbes cartoon making the same point.[313] Understanding, and self understanding, might yet rescue us — 'All science asks is ... the same levels of scepticism we use in buying a used car' (Sagan, end of Chap. 4) — but it is going to be a close run thing.

136. M. E. McIntyre: 'Lucidity and science. I: Writing skills and the pattern perception hypothesis', *Interdisc. Sci. Rev.*, 1997, **22**(3), 199–216; and 'Lucidity and science. II: From acausality illusions and free will to final theories, mathematics, and music', *Interdisc. Sci. Rev.*, 1997, **22**(4), 285–303. The 'walking lights' phenomenon is described on p. 203 and in Ref. 31 of Part I. A demonstration is available on the Internet.[277] The 'heteroactive barber', who by definition shaves those and only those who do

not shave themselves, is discussed on p. 205 of Part I. To see that this is a self-contradictory definition, a conscious effort is required; the language instinct does not automatically check for self consistency. The unconscious drive to prune combinatorial trees of possibilities is discussed on p. 291 of Part II. The distinction between humility and apology is discussed in Part II, in the section on epistemology and final theories.

137. E. F. Keller: 'Science and its critics', in 'The Future of academic freedom' (ed. L. Menand), 199–213; 1996, Chicago, University Press, 239 pp. This thoughtful and serious discussion bears on the sociology of research and contributes to 'science wars' conciliation.[235] So also does N. D. Mermin: What's wrong with this reading?', *Physics Today*, 1997, **50**(10), 11–13, giving a scientist's viewpoint. Both articles plead for care in using the highest professional standards of argument, with clear examples of how misunderstanding can arise in discussions of science and its cultural and sociological aspects. For correspondence arising from Mermin's article, see *Physics Today*, 1997, **51**(4), 15 and 102–104.

138. R. Barker: 'And the waters turned to blood: the ultimate biological threat'; 1997, New York, Simon and Schuster, 352 pp (ISBN 0684831260). A single cell organism, *Pfiesteria piscicida*, has recently destroyed fisheries in the Chesapeake Bay region of the USA and made the water too dangerous for humans to swim there. It is suspected that this sudden development, thought to be unprecedented, was an adaptation triggered by the buildup of chemical pollution, perhaps destroying whatever the organism used to feed on. If confirmed, this would illustrate what is self evident, in any case, from the slightest knowledge of biological systems, namely that when you change an environment then you must expect to see evolutionary adaptations of one kind or another. See also Note 139:

139. The recent evolution of transmissible spongiform encephalopathies, such as bovine spongiform encephalopathy (BSE or mad cow disease),[270] must count as another clear example — fundamentally like that just mentioned[138] — if you are prepared to regard the feeding of meat products to herbivores as 'pollution' in the relevant sense, that of exerting new and unknown selective pressures on disease agents.

140. M. Piattelli-Palmarini: 'Inevitable illusions: how mistakes of reason rule our minds'; 1994, New York, Wiley, 242 pp. Includes comments on sales pitches and 'positioning'; *see* the example in Note 35 of Part I. *See* also Refs. 188.

141. The false dichotomization of science into 'revolutionary' and 'normal' — as if there were nothing in between — seems to me to have been Thomas Kuhn's, or at least his followers', most profoundly damaging mistake.[134] Kuhn's two categories are only the extremes of a problem solving continuum. Far closer to the mark, meaning far closer to the actual experience of working scientists like myself, is the wonderfully perceptive discussion by Robert Pirsig;[278] *see* also, for instance, Note 279 below, Note 34 of Part I, and the essay by P. Medawar: 'Hypothesis and imagination', in 'Pluto's Republic'; 1982, Oxford, Oxford University Press, 351 pp. (Also in 'The art of the soluble'; 1967, London, Methuen.) This last is a spirited defence of the role of imagination and intuition — the crucial importance of the unconscious side of scientific thinking — at all points of the problem solving continuum: 'The belief that great discoveries and little everyday discoveries have quite different methodological origins betrays the amateur.'

142. The difficulties are compounded, of course, by the multiplicity of superficial forms that a given model may take, on top of the need to work with hierarchies or ensembles of different models having different accuracies and different purposes, which is something the brain seems to do unconsciously in any case.[280]

The essence of the matter can be seen from the example of children's model houses, boats, and trains, an example sometimes regarded as trivial. As well as being real objects these are models, not only in the child's intuitive sense, but also in the general sense used here and throughout science: they are — more precisely, they can be used as — partial and approximate representations of reality. A model house, whether simple or elaborate, represents some aspects, though not others, of a 'real' house. Some models are more accurate than others, and emphasize some aspects of real houses more than others. Models with electric lighting delighted me as a small child. I never saw one with foundations or plumbing, nor an accurate representation of how real roofs keep rain out. So one can have hierarchies or ensembles of different models for different purposes.

Models need not be made of solid materials: they can be made of neuromolecular patterns or of computer code, as 'virtual reality' displays remind us. Such displays are generated by computer codes, but are very like children's models. They are visually equivalent to three-dimensional objects that represent, in a simplified way, some aspects, though not others, of real houses, or real anything else. The equivalence would not be obvious from inspecting the computer code, and this is a crucial point: the same model can have very different representations, whose equivalence may be anything but obvious.

Since models can be made of computer code they can also be made of mathematical equations, as already implied by the arguments in Part II. Mathematical equations can be looked on as a kind of generalized computer code — as instructions to perform some computation, such as finding the elements of a set (cf. perceptual grouping). In some ways, mathematics takes us far beyond what computers can do, because mathematics has ways of dealing with infinite numbers of cases simultaneously, and with notional computations that have infinite numbers of steps.

All these considerations apply, in particular, to the great models, the great theories, of classical and quantum physics. A single model or theory can be expressed in many different forms whose equivalence may well be far from obvious on inspection. Examples include the equivalence of various differential and integral formulations — as Richard Feynman once said in a famous interview, 'psychologically very different'. These go all the way from geometrical optics and Hamilton's principle to quantum theory and path integrals. Another example, perhaps the most famous of all, is the equivalence of Heisenberg and Schrödinger representations of quantum dynamical systems, an equivalence recognized, in 1926, only after months of 'driving in the fog' by some of the greatest scientists of the day.

143. S. Fuller: 'Is science policy superstitious? The view from Mars', *Interdisc. Sci. Rev.*, 1997, **22**, 194–198. The author, a sociologist, answers 'definitely yes', and with some justification — though his ideas on what to do about it are quite different from mine. This article seems typical of the 'science wars' literature,[235] very much in line with the 30th Anniversary BBC Horizon programme.[232] It minces no words about science as something 'loathsome'. It is worth reading in order to get an idea of the sort of fury that has been evoked by attempts to sell Science as the Answer to Everything.[255] Afterwards, I recommend reading Refs. 137 and 224.

144. Y. Fern: 'Gene Roddenbury: the last conversation — a dialogue with the creator of Star Trek'; 1994, University of California Press, 228pp (reviewed by L. J. Sage: *Nature*, 1995, **372**, 141). The review makes an interesting case for the role of science fiction in helping with the public understanding of science. Roddenbury and his character Spock 'take a positive delight when someone says "I disagree with you because ..." ' — the delight of serious discussion and argumentation, with no thought of personal rancour, no thought other than to get a problem solved. (This for me is exactly what makes life as a scientist worth living.) A thoughtful *Nature* editorial, 1998, **394**, 815, has suggested a similar role for the much-derided television series *The X-Files*. 'Mulder and Scully... look at the evidence, they come up with hypotheses, they test them, and most are found wanting. Any truth that they think they find is soon undermined by new evidence... The popularity of *The X-Files* suggests that the public clearly has more of a feeling for the spirit of scientific enquiry than some give it credit for.' See, however, the letters from John Durant in **395**, 110 and Daniel Davies in **395**, 740. The whole debate poignantly hints at the deeply nontrivial nature of the 'public understanding' problem and of what is involved in 'the spirit of scientific enquiry'. Davies points to the false perception, to which scientists have unfortunately contributed, that 'there is no longer any mystery that science cannot elucidate' — that science has robbed us of the chance to experience the mysterious and the awesome — a false perception betraying ignorance of what science is and how it works.

145. L. Wolpert: 'The unnatural nature of science'; 1992, London, Faber, 191 pp. *See* also Note 48 of Part I. Gives a very clear explanation of the *difference* between commonsense knowledge and scientific knowledge, with emphasis on the intellectual courage required to reach the latter, the courage required to take the scientific ideal seriously.

146. J. S. Bell: 'Speakable and unspeakable in quantum mechanics'; 1987, Cambridge, Cambridge University Press, 212 pp. A classic collection of lucid and penetrating discussions about quantum mechanics and its incompleteness (*see* also main text above). As often happens, some of the trouble in developing scientific theories comes when (pp. 165–6) we fail to ask *which experiment?* or *which thought experiment?* In the latter connection *see* also Chap. 9, 'How to teach special relativity'. This beautifully shows the desirability of getting more than one angle on a problem before claiming good understanding.

147. D. Deutsch: 'The fabric of reality'; 1997, London, Allen Lane, 390 pp. This wonderfully perceptive, provocative, and erudite book is, in many important ways, if you read between the lines, less dogmatic than its more breathtaking assertions might tend to suggest. Further notes are given in Note 293a of `lucidity.ps` on the Internet.[277] In brief, the book talks a great deal about 'truth', but mostly in a clear-headed way that is concerned with 'reality', 'truth', and 'understanding' in what I am going to call the scientist's shorthand sense, which (p. 241) 'precludes the possibility of certainty' — even though, in other places, the author conveys the strong impression that he is, on the contrary, claiming absolute certainty about certain aspects of quantum mechanics (discussed in the main text above) that are incompletely understood and highly speculative.[146,210–221] Chap. 7 of the book also gives, among other things, an excellent, and superbly lucid, philosphical discussion of the practical workings of the scientific ideal, similar in spirit to my briefer version in the section 'On epistemology ...' in Part II and emphasizing Popper's important and much misunderstood contributions.[148] Chap. 13 gives an excellent characterization of the scientific ideal and ethic in action (pp. 325–7): 'You need only attend a research

seminar in any fundamental field in the "hard" sciences to see how strongly people's behaviour *as researchers* differs from human behaviour in general ...' This has been exactly my own professional experience.

148. K. Popper: 'Unended quest', revised edn; 1992, London, Routledge and Kegan Paul, 276 pp, & refs. therein. This is Popper's personal overview of his own philosophical development, including development of the notions of 'closeness to the truth' and of science and ordinary perception as model-fitting, equivalently 'conjecture and refutation'. *See* also Ref. 147, and Note 45 of Part I. For examples of what I mean by 'misunderstood', *see* Ref. 93 of Part II and the second of Refs. 236 below.

149. R. Penrose: 'Shadows of the mind: a search for the missing science of consciousness'; 1994, Oxford, Oxford University Press, 457 pp. The book is very clear on quantum mechanical fundamentals and their strange implications (Chaps. 5 and 6, pp. 237–347), including the fact, obscured by most quantum textbooks, but well verified experimentally, that certain very special kinds of measurements, sometimes called 'null measurements', do not disturb a system.[310] More in Notes 53 and 231*d* of `lucidity.ps` on the Internet,[277] and in the Appendix to Part II.

150. S. Weinberg: 'Dreams of a Final Theory — the search for the fundamental laws of nature'; 1993, London, Vintage Books, 260 pp. This is one of the most eloquent and cogent non-specialist discussions I have read on just how far we have come in physics by using the power of mathematics — using the requirement for self consistency in model building together with the strongest form of Occam's razor: the assumption, or faith, that the relevant simplicity includes aesthetic considerations of elegance and beauty. *See* also Ref. 265. The book also reminds us, together with Ref. 147, how deeply embedded is the inclination, in some of our most brilliant physicists' minds, to make an absolute distinction, a false dichotomization, between 'mere models' and 'true theories' — as distinct from a judgment of the goodness of a model or theory in terms of its accuracy, beauty, economy, and insightfulness.

151. Schoolchildren — most if not all schoolchildren, not just a privileged minority — could perfectly well be exposed to the idea that science is about solving problems and puzzling out how things work, and about living with uncertainty and even, dare I say it, being allowed to fail — rather than science being about absolute truth and the parroting of credos, the rote-learning of strange words and mantras demanded by the audit culture's[198] tests and league tables. Children can perfectly well be exposed to solvable puzzles that demonstrate simple but counterintuitive realities, not just spinning gyroscopes but also simple counterexamples to 'seeing is believing'.[307] And every schoolchild with normal vision could be shown the 'walking lights' or similar demonstrations and could be challenged with questions like 'How do you know — *do* you know — that you are looking at a person walking?'[136] Indeed, there is nothing to stop demonstrations of such perceptual phenomena appearing, routinely, as animated logos on the screen of every child's computer. One of them is already an animated logo on my Internet home page.[277]

152. B. Martin *et al.*: 'The relationship between publicly funded basic research and economic performance — an SPRU review [report prepared for HM Treasury by the Science Policy Research Unit at Sussex University]'; 1996, London, Her Majesty's Treasury (fax +44-171-270-5244). The terms of reference were to review the literature on the relation between basic research and economic performance, the same question as from science minister Ian Taylor earlier in 1996: 'What does Britain gain from ... money spent on funding basic research?', meaning commercial gain. The report points out that 'current methodologies for measuring such benefits are seriously flawed', and why. For instance, beyond published output, 'Research is also a learning process, yielding "tacit" knowledge in terms of the skills and routines without which it is not possible to make use of state of the art ideas and techniques.'

153. R. Milner: 'Semantic ideas in computing', in 'Computing tomorrow: future research directions in computer science', (ed. I. Wand and R. Milner), 246–283; 1996, Cambridge, Cambridge University Press, 373 pp. This surveys a research programme that promises deep, general, and practically useful insights into what is involved, conceptually, in building reliable and maintainable computer software. Today's typical haphazard, and hazardous, short-term or hand-to-mouth approach could be superseded, in future, by one in which we have a deeper understanding of what is done with computers and how to use them safely.

154. R. J. Anderson: 'Cryptography in Europe — markets, law and policy', 1996. In: 'Cryptography: policy and algorithms', 1996, Springer Lecture Notes in Computer Science **1029**, 75–89, ed. E. Dawson. Also available at ftp://ftp.cl.cam.ac.uk/users/rja14/queensland.ps.Z on the Internet. This short, cogent, and well documented essay takes a close look at one of the present battles between nationalist and supranational forces, which supranational forces, working largely out of sight of ordinary politics, already seem likely to win for a combination of overwhelming economic and technological reasons including the need, as yet unmet, for secure and independently auditable electronic transaction systems. Exactly where all this will lead is, of course, unclear as yet;[281] but it does seem to be working against ordinary

totalitarian tendencies, against total censorship and control by particular commercial interests or by small groups of politicians. Arguably, this is a wholly unprecedented situation in human history, and part of what might allow democracy, in some form, to survive against the odds,[263,314] even if not in what many would call an ideal form.[308]

155. E. von Weizsäcker, A. B. Lovins, and L. H. Lovins: 'Factor four: doubling wealth, halving resource use — the new report to the Club of Rome'; 1997, London, Earthscan Publications, 322 pp., ISBN 1 85383 407 6, `http://www.earthscan.co.uk`. An important book presenting hard-headed economic arguments based on many well documented, detailed examples of what has happened and what is happening. It brings out the increasing scale of devastation caused by market forces run wild: *see*, e.g., in Chap. 13, references to Richard d'Aveni's promotion of 'hypercompetition', of economic competition as a form of total warfare, the aim being annihilation of your competitors regardless of the human, social, or environmental consequences.[281] Along with Refs. 255 and 156 'Factor Four' also shows, on the other hand, with detailed examples, how market forces can be — and have been — put to work constructively and sustainably. Such a change in the use of market forces illustrates what I mean by organic cultural change, helped by respect for the scientific ideal in the sense I am using the phrase: respect for coherence and self consistency, for what hangs together and makes sense. For further discussion of some of the rethinking now going on among economists and ecologists, *see* also the 1 October 1998 issue of *Nature*: Ehsan Mahsood and Laura Garwin: Costing the earth: when ecology meets economics (Briefing), *Nature* **395**, 426–430; Don Fullarton and Robert Stavins: How economists see the environment (Commentary), *Nature* **395**, 433–434; and Bridging economics and ecology (Editorial), *Nature* **395**, 415. For yet another angle on all this, *see* Ref. 314.

156. J. J. Berger: 'Charging ahead: the business of renewable energy and what it means for America'; 1997, New York, Henry Holt, 399 pp., ISBN 0 805 037 713. The author, John J. Berger, 'has apparently talked to almost everyone involved' in the US renewable energy industry, and the book includes 'many fascinating case studies': *see* the review of this and Ref. 155 by Robert Day in *Nature*, 1997, **389**, 247–248. Berger argues that renewable energy technology will soon be advanced enough to be competitive, despite the present large government subsidies to non-renewables like fossil fuels.[155,247]

157. The 'growing threat from biological terrorism' was the subject of an expert conference in August 1997 (*Nature*, 1997, **388**, 703). Biosensors useful for food safety inspection and disease epidemic monitoring are already under development; but the combinatorially large number of possibilities makes it likely that new concepts and strategies will be needed as well.[204]

158. S. O. Andersen and A. Miller: 'Ozone layer: the road not taken', *Nature*, 1996, **382**, 390. This briefly but cogently argues for the enormous benefits, political and economic, of allowing technologies and markets to respond early to environmental change — the benefits of keeping our collective heads out of the sand. The 'ozone wars' of the 1970s and 1980s and their resolution provide a telling example, and reason for hope. Once the scientific picture became clear enough, 'industry helped policy-makers to choose schedules that were technically feasible and allowed time for wise choice' while, conversely, a late start would have forced industry and customers 'to select from among the very first technologies available', reducing cost effectiveness as well as public confidence. Earlier action would have been still more beneficial.

159. J. Keats: 'On first looking into Chapman's Homer'; 1817.

160. E.g. K. Popper: 'The open society and its enemies', 5th edn, Vol. 2; 1966, London, Routledge and Kegan Paul, 420 pp. *See* also, among very many others, Refs. 135, 172, 191, 229, and 247.

161. C. Wills: 'The runaway brain'; 1994, London, HarperCollins, 358 pp. Presents abundant and cogent evidence — *see* for instance discussions of genotype–culture feedbacks and the 'Baldwin effect'[171] — for a most intimate and subtle interplay between nature and nurture, between biological and cultural evolution. Further comments in Note 13 of Part I. *See* also Ref. 171 and S. Jones: 'In the blood'; 1996, London, HarperCollins, 302pp., a witty and insightful extended essay, by a professional geneticist, on what we know and do not know about human genetics and its social relevance. Jones takes good care to debunk the simplistic racist, eugenics, nature–nurture and genetic engineering myths. On these last points *see* also, for instance, among many others, Refs. 169–171 and Note 162:

162. Genetic engineering, it should be recalled, is not what popular mythology and science fiction often assume. Despite being useful, very probably, for repairing isolated damaged genes, it cannot meddle with the Platonic. It cannot 'reprogram DNA',[130,282] meaning human DNA, in the sense of making or unmaking parts of genetic memory, of reprogramming the 'collective unconscious'[283] No one knows, nor is anyone likely to know in the foreseeable future, how to begin to write such 'programs', let alone how to do so safely — to do so in an error-free manner whose consequences are predictable or even pre-testable. We are barely beginning to understand how to do such things for standard electronic computers, a relatively simple matter.[153] And it ought to be explained more often that genetic memory

is unbreakably encrypted in myriads of genes. An educated guess is that the human genome will prove to have something of the order of 100 000 genes (J. E. Sulston, personal communication), of which something like 30 000 are probably active, and interactive, within the brain, according to Jones' book, the second of Ref. 161, p. 219. Even larger numbers might, conceivably, be relevant in one way or another: we should not think of the brain as if it were isolated, not intimately connected to other parts of us. By 'unbreakably encrypted' I mean that the genome is unreadable by humans with comprehension of how it functions as a whole, of how tens of thousands of genes interact with each other and with the rest of the organism, and with its history and with its environment including the effects of other organisms, of how, when, and why genes are turned on and off and what chains of consequences may follow. The genome is unreadable in this sense even with the help of our most powerful electronic computers, which, it should be remembered, cannot even take as input the far smaller genome of a single bacterium and predict the bacterium's behaviour.[284] Growing the bacterium itself is still the only known way to 'perform' such a 'computation', and the same goes for humans *a fortiori.* To point to a vastly simpler case, relevant in some ways though not others, we cannot even tell by inspecting the simple equation $z_{n+1} = z_n^2 + c$ that it contains, implicitly, the infinitely intricate shape of the Mandelbrot set.[186]

163. There could be no more telling example of such underestimation than the US State Department's mistake over Bosnia, in thinking of the Bosnian and other Balkan problems as 'only religious' [*sic*] — as if that made them minor problems. According to a lecture by Conrad Russell on BBC Radio 3 (8 August 1995), this showed a profound ignorance not only of human nature but also of the historical record, for instance of the meticulous factual studies of past 'religious' turmoil by the respected historian Dame (Cicely) Veronica Wedgwood. *See* also, for instance, Refs. 166 and 195.

164. P. J. Williams, Patricia J., 1997: 'The Geneology of Race — Towards a Theory of Grace', Reith Lectures, British Broadcasting Corporation, London, July 1997.

165. On medieval witch hunting, *see* Chaps. 7 and 24 of Ref. 135, also p. 29. Chap. 7 mentions Thomas Ady, and Chap. 24, written in collaboration with Ann Druyan, mentions, and extensively quotes from, Friedrich von Spee. Ady and von Spee dared to publish, in 1656 and 1631 respectively, exposés of witch mania. *See* also Note 194.

166. B. Ehrenreich: 'Blood rites: origins and history of the passions of war'; 1997, London, Virago/Little, Brown, 292 pp. Especially when read alongside Ref. 173, this is the most cogent attempt I have seen to explain what is perhaps the oldest of all ritual magic — whose power is still wielded today, with terrible effect[285] — the evocation of the religious ecstasy of war and martyrdom and the transformation of ordinary humans, male or female, into killers or sacrificial offerings or both. The book points out the likely prelinguistic origins, going back 2 million years or more, of the associated behaviour patterns and animistic–theistic imagery. The suggested reason is straightforward and highly plausible: the dependence on the activities of large predators, as well as exposure to attack by them, that is likely to have been associated with our ancestors' transition to a migratory, ground dwelling existence in open country around 2 million years ago.[173] Lacking, at first, highly developed hunting skills and weapons, those early ancestors of ours would not only have been regular victims of large predators but would also, very probably, it is argued, have depended on scavenging from kills of other large animals by the same predators — contributing to the high quality diet both demanded by, and made possible by, increasing brain size and tactical cunning and daring.[189,173] This may have been part of what drove the first episode of brain expansion seen in Fig. 1. Such a scenario, followed by the transition to being predators ourselves, well explains why our psyches and mythologies are so full of deities that combine the roles of fickle benefactor and devouring monster, to whom humans must be prepared to become martyrs for the sake of the group or tribe and with whom humans must also, from time to time, do battle — what is called fighting with dragons[189] or wrestling with angels.[283]

167. S. Pinker: 'The language instinct: the new science of language and mind'; 1994, London, Allen Lane (Penguin), 494 pp. Pinker is aware of the scope for misreading the word 'instinct', and explains it carefully at the outset. The essence is to recognize that memes as well as genes are involved, together with their complex interactions — that the word 'instinct' ought not to be linked to the old, simplistic, and manifestly wrong idea of 'brutal biological determinism'.[129] For other comments on this important book *see* Note 12 of Part I and the fuller version thereof in the file `lucidity.ps` on the Internet.[277]

168. 'Memetic' is from 'meme' as 'genetic' is from 'gene' — a meme being an infectious idea that can self replicate and undergo mutation, an element of cultural evolution. Thus one can reasonably describe as 'genetic–memetic' the intricate and complex interplay of co-evolving genes and memes, the nature–nurture dynamic,[161,171] the evolutionary processes that shaped our ancestors together with the group dynamics that was their means of survival.[166,173,174] The word 'meme' was coined by Richard Dawkins in his justly famous though much misunderstood[129] 1976 book, 'The selfish gene'; *see* also, for instance,

R. Dawkins: 'The blind watchmaker'; 1986, London, Longman/1988, London, Penguin, 332 pp., and, for instance, O. R. Goodenough and R. Dawkins: 'The "St Jude" mind virus', *Nature*, 1994, **371**, 23–24. *See* also the brief but magnificently lucid discussion in Ref. 174.

169. P. Medawar: 'Science and the sanctity of life', in 'Pluto's Republic', 311–323; 1982, Oxford, Oxford University Press, 351pp.

170. K. E. Davies, A. J. Clarke, and P. S. Harper: 'The genetic revolution and medicine in the 21st century', *Europ. Rev.*, 1997, **5**, 39–54. 'Is having the wrong genes going to become an acceptable line of defence in a court of law in cases of violence? Fortunately, ... the biological basis of behaviour ... is unimaginably complex, and is open to modification by numerous environmental influences.'

171. J. Cohen and I. Stewart: 'The collapse of chaos: discovering simplicity in a complex world'; 1994, New York and London, Penguin, 495 pp. *See* for instance the excellent discussion of the intimacy of nature–nurture interactions, 'a rich, fascinating, and largely unexplored joint dynamic', p. 314ff., showing, like Wills,[161] Kauffman,[204] and others, how genes are only part of an extremely intricate story. *See* for instance the section on 'genetic assimilation', otherwise known as the 'Baldwin effect'.[161]

172. M. Walzer: 'On toleration'; 1997, London, New Haven, CT, Yale University Press, 126 pp. A wise, deeply thoughtful, humane, and practical view of the relevant history and its implications — of the several ways in which the human societies of the last two and a half millennia have, rarely, found it possible to tolerate different belief systems within them, and of the social conditions that might be crucial to such toleration in the future. The last two chapters explore ways toward what might be called constructive tribalism; *see* also Ref. 273. In his discussion of the most recent kinds of relatively tolerant society, what we call the free market democracies, dependent on the separation of church and state and on having a secular 'civil religion' of national stories, heroes, celebrations etc., hence national identity, Waltzer points out that 'toleration is most likely to work well when the civil religion is least like a ... religion' (p. 77), and furthermore that 'Democracy requires yet one more separation, one that is not well understood: that of politics itself from the state ... The winning party, though it can turn its ideology into a set of laws, cannot turn it into the official creed of the civil religion; it cannot make the day of its ascension to power into a national holiday, insist that party history be a required course in the public schools, or use state power to ban the publications or the assemblies of other parties. This is what happens in totalitarian regimes, and is exactly analogous to the political establishment of a single monolithic church' (pp. 81–82). *See* also M. Perutz, 1997: By what right do we invoke human rights? *Europ. Rev.*, **5**, 123–133, & refs. therein. Also the wonderfully wise, humane, and erudite historical essays of Isaiah Berlin.[318]

173. L. C. Aiello: 'Terrestriality, bipedalism and the origin of language', *Proc. Brit. Acad.*, 1996, **88**, 269–289. Reprinted in: W. G. Runciman, J. Maynard Smith, and R. I. M. Dunbar (eds.): 'Evolution of social behaviour patterns in primates and man'; 1996, Oxford, University Press and British Academy, 297 pp. The best brief survey I have seen on the palaeoanatomical evidence, valuably supplementing Wills' book.[161] On the shrinking of (central African) forests in glacial times, see especially the recent news item by Peter D. Moore in *Nature*, 1998, **391**, 124–126 & refs., discussing the multi-site pollen study by D. Jolly et al., *J. Biogeogr.*, 1997, **24**, 495–512.

174. J. Monod: 'Chance and necessity', (trans. A. Wainhouse); 1971, Glasgow, Collins, 187 pp. A lucid and penetrating discussion of what was already known, in the 1960s, about molecular-scale cybernetics; *see* also Ref. 204 and Notes 2–4 of Part I. Monod also offers, in the final chapter, some important and clearheaded suggestions about human nature and belief systems and their likely genetic–memetic evolution.[168] Monod suggests that 'the ideas having the highest invading potential' — in today's language, the most powerful memes — 'are those that *explain* man by assigning him his place in an immanent destiny, a safe harbour where his anxiety dissolves.' Monod further emphasizes what must have been 'the extreme subjective power of the laws that organized and guaranteed this [tribal] cohesion', whence 'the need for an explanation, the profound disquiet which forces us to search for the meaning of existence ...',[134] giving rise to 'all myths, all religions, all philosophies and science itself.'

175. C. Blakemore: 'Mechanics of the mind'; 1977, Cambridge, Cambridge University Press, 208 pp.

176. E.g. M. Gopnik, J. Dalalakis, S. E. Fukuda, S. Fukuda, and E. Kehayia: 'Genetic language impairment: unruly grammars', *Proc. Brit. Acad.*, 1996, **88**, 223–249. Reprinted in: W. G. Runciman, J. Maynard Smith, and R. I. M. Dunbar (eds.): 'Evolution of social behaviour patterns in primates and man'; 1996, Oxford, Oxford University Press/British Academy, 297 pp. This presents strong psychophysical evidence that the impairment of syntactic or grammatic function, such as the ability to form regular plural nouns from newly encountered singular nouns, as with 'wugs' from 'wug', can be a heritable genetic defect.

177. Notes 41–44 of Part I, underlining the biological importance of juvenile play, contain one mistake and one dubious statement. Note 41 about Gregory Bateson's writings should have referred to the

essay ‘A theory of play and fantasy’, which appeared in G. L. Bateson: ‘Steps to an ecology of mind: collected essays on anthropology, psychiatry, evolution and epistemology’, 1972 and 1973: San Francisco, CA, Chandler/London, Intertext/ London and Northvale, New Jersey, Aronson/London and New York, Paladin; 545 and 510 pp. The dubious statement occurred in Note 43, and claimed what seems, in the light of Fig. 1 and its discussion in Ref. 173, to be possibly too long a timespan for the likely existence of what we might today call poetry. See also Wills[161] p. 249.

178. J. Kegl, A. Senghas, M. Coppola: ‘Creation through contact: sign language emergence and sign language change in Nicaragua’, in ‘Comparative grammatical change: the intersection of language acquisition, creole genesis, and diachronic syntax’, (ed. M. DeGraff); 1998, Cambridge, MA, MIT Press. In press. *See* also J. A. Kegl and J. McWhorter: ‘Perspectives on an emerging language’, in Proc. 28th Annual Child Language Research Forum (Stanford) (ed. E. V. Clark), 15–38; 1997, New York and Cambridge, Cambridge University Press and Palo Alto, CA, Center for the Study of Language and Information.

179. New information from the palaeoclimatic isotope and other records for the past 100 millennia or more shows large and rapid climate fluctuations, at ever improving time resolution and in an increasing number of ways, especially in ice core records over the last few tens of millennia. Particularly striking is the evidence in L. G. Thompson *et al.*: ‘Tropical climate instability: the last glacial cycle from a Qinghai–Tibetan ice core’, *Science*, 1997, **276**, 1821–1825. This core from the Guliya ice cap shows persistent oscillations of about 200 year period whose large amplitude suggests drastic fluctuations in the Asian monsoonal circulation. With a timescale for significant change of the order of 3 decades (200 years/2π), this means very large changes within an individual’s lifetime. The oscillations studied in detail — about 100 of them in more or less continuous succession — occupied a time interval centred on about 28 millennia before the present. So if one human generation took 20 years or less, then at least 1000 generations of humans would have been subject to ceaseless environmental fluctuations over this period alone. The love of storytelling, so deep-rooted in us today,[180,222] could well have been an important aid to a tribe’s memory of past climate oscillations and how to survive them. *See* also Note 185.

180. The UK Society for Storytelling has plenty of evidence, if such is needed. Given a little encouragement, children will ‘automatically’ create and tell their own stories ... ‘one form of *Let’s Pretend*’ ... ‘everyone can do it’ ... ‘just a matter of boosting confidence’ ... ‘eye contact is important’ ... ‘when the imagination is engaged, people come alive’ ... ‘everyone has a story ...’, etc. (BBC1 Television, 14 August 1997). I have a clear recollection of improvising fairly elaborate stories myself, as an 11 year old, for my younger brother and sister, and even writing them down. (Professional storytelling for *adults* is of course a multi-billion-dollar business, in the guise of what the US National Speakers’ Association calls ‘motivational speaking’ — ‘the showbiz of business’, the business of ‘stories to open your heart and rejuvenate your spirit’ as salespeople and business executives.)

181. Not surprisingly from this viewpoint, ‘rhetorical and poetic speech forms’, as well as music, have been noted in many so called primitive cultures, e.g. by the anthropologist Donald E. Brown (Ref. 167, p. 413).

182. For further examples of the ever-changing usage of the English language — accelerated, one presumes, by today’s amplified political and newsmedia pressures — *see* D. Crystal: ‘The Cambridge encyclopaedia of the English language’; 1995, London, BCA, by arrangement with Cambridge University Press, 489 pp. *See* also the remarks about ever-changing *scientific* usage in Notes 11 and 66 of Part I and in the Appendix to Part I.

183. E.g. S. Mithen: ‘The early prehistory of human social behaviour: issues of archeological inference and cognitive evolution’, *Proc. Brit. Acad.*, 1996, **88**, 145–177. Reprinted in W. G. Runciman, J. Maynard Smith, and R. I. M. Dunbar (eds.): ‘Evolution of social behaviour patterns in primates and man’; 1996, Oxford, Oxford University Press/British Academy, 297 pp. This interesting and scholarly discussion, with an extensive bibliography, concentrates on prehistoric visual art objects and their social uses such as body adornment with beads, bracelets, and pendants. Such art objects are evident in the archeological record for the Upper Palaeolithic, the last few tens of millennia of the unstable glacial climate starting between about 35 and 60 millennia ago in different parts of the world. For the preceding period going back perhaps several hundred millennia, called the Early Palaeolithic, there is strong evidence from ‘numerous well preserved sites’ that ‘no objects of art were produced’. The author suggests that the transition to cultures that made visual art objects signalled ‘a dramatic increase in cognitive fluidity’. It is difficult, however, to believe that the genome could have changed quite as suddenly as that would imply. As today, it could have been simply a cultural sea change.[286]

184. Our closest living non-human relatives, the chimpanzees, have been observed to go to war in the sense that, when living freely under natural conditions, one small community of chimpanzees exterminated

another and took over their territory. *See* Chap. 10, 'War', of J. Goodall: 'Through a window: My thirty years with the chimpanzees of Gombe'; 1991, Boston, Houghton Mifflin, 268 pp. Also R. W. Wrangham: 'Demonic males: apes and the origins of human violence', 1996, Boston, Houghton Mifflin, and 1997, London, Bloomsbury, 350 pp.

185. G. Bond *et al.* : 'Correlations between climate records from North Atlantic sediments and Greenland ice', *Nature*, 1993, **365**, 143–147, & refs. therein to celebrated work by Dansgaard and Oeschger ('Rates of change in ... ocean temperatures must have been ... several degrees within decades' in the North Atlantic region). *See* also, for instance, J. P. Severinghaus *et al.*,: 'Timing of abrupt climate change at the end of the Younger Dryas interval from thermally fractionated gases in polar ice', *Nature*, 1998, **391**, 141–146. This shows very clear evidence from a Greenland ice core, obtained using a new technique, for a step-like temperature rise 'in less than a decade', of magnitude tentatively estimated at 5–10°C, marking the end of the so called Younger Dryas cold interval eleven and a half millenia ago. This event appears to have been the last of many abrupt warmings before the climate became relatively stable around ten millennia ago. I am grateful to Lonnie Thompson and Nicholas Shackleton for expert advice on these matters.

186. I. Stewart: 'Does God play dice?', 2nd edn; 1997, London, Penguin, 401 pp. A good introduction to the so called chaos theory of Poincaré and his successors. Along with Ref. 171, this book also gives an insightful view of how science works as a model-fitting process, and why mathematics is relevant: 'To criticize mathematics for its abstraction is to miss the point entirely' (p. 363). My remarks in Part II about the unconscious power of abstraction (last two sections and Appendix) are, in effect, an elaboration of this point.

187. With this article nearly in press I have just come across a possible alternative, or complementary, term 'simplex thinking', on pp. 289–291 of a new and interesting book by I. Stewart and J. Cohen: 'Figments of reality: the evolution of the curious mind'; 1997, New York and Cambridge, Cambridge University Press, 325 pp. The term 'simplex thinking' is attributed to S. R. Delaney. One of my themes is today's audit culture[198] and its hypercredulous aspects; and Stewart and Cohen make a related point on their p. 295: 'Simplex officialdom sees scientific research as anarchy, and is convinced that with a bit of organization the whole thing would function far more efficiently. But a multiplex view shows just how wrong this is ...' The point is then illustrated by describing a technological advance, the X-ray lens, likely to lead to another big speedup in silicon microchip technology hence industrial exploitation on a multibillion dollar scale. It is very clear that this advance — like many other advances of exceptional importance — could not possibly, by the wildest stretch of imagination, have been anticipated by any technology 'foresight' exercise.[250] Starting about 20 years ago, the X-ray lens was suggested by biology and developed for astronomy. One is tempted to say that if hypercredulity is to be called simplex thinking, and lateral openmindedness multiplex thinking, then dichotomization could perhaps be called duplex thinking. The book is a followup to Ref. 171; on p. 87 I notice, in addition, that it gives a clear explanation of the *mitochondrial Eve fallacy*, instructive as 'yet another mistake brought about by taking the DNA-as-blueprint image too literally'.[129]

188. M. L. J. Abercrombie: 'The anatomy of judgment: an investigation into the processes of perception and reasoning'; 1989, London, Free Association Books, 156 pp. *See* also Note 34 of Part I. Also, e.g., Ref. 140 above, and E. de Bono: 'Practical thinking'; 1971, London, New York, Penguin (republished 1976), 189 pp. *See* also Note 36 of Part I.

189. O. R. Frisch: 'What little I remember'; 1979, Cambridge, University Press, 227 pp. On the discovery of nuclear fission, *see* p. 116. For a first hand account of what came close to being a fatal accident, during Project Manhattan, with a near critical mass of fissile material, *see* p. 161. Richard Feynman called it 'tickling the tail of a sleeping dragon' (p. 159; *see* also Note 166 above). Another episode described on p. 161, leading to one of the two fatal accidents that did occur, provides us with what strikes me as an excellent illustration of the human gambling instinct at work, even in the subconscious mind of an 'experienced and cautious physicist'. (This is gambling for thrills, not money; but I think the instinct is the same. I have felt it myself when flying gliders solo, and noticed the conscious effort needed to control it. Politicians do it for power.[270])

190. G. Born: 'Problems with limits', *Science and Public Affairs* (London, Roy. Soc.), 1991, **6(2)**, 17–25. Gustav Born puts on record the passage written by his father, Max Born, and quoted here in the main text. He also discusses the limitations of science, which many working scientists have long appreciated,[287] contrary to impressions that might be given by, for instance, Ref. 134.

191. J. Bronowski: 'The ascent of man'; 1973, London, British Broadcasting Service/New York, Boston, Little Brown, 448 pp.

192. J. Kevorkian: 'Prescription: medicide — the goodness of planned death'; 1991, Buffalo, NY, Prometheus Books. 268 pp. (ISBN 0 87975 677 2; available from bookshops and from The Right to Die

Society of Canada, P. O. Box 39018, Victoria, British Columbia, Canada V8V 4X8.) This remarkable book presents an outspoken and well documented personal view, based on clear thinking, careful observation, and an exceptional, perhaps unique, fund of experience. It shows the scientific ideal and ordinary human compassion both being applied in the legal and political front line of battle for what most people would call civilized values. The human and social problems he addresses are little recognized because of present taboos against discussing them seriously. Kevorkian's experiences of observing the reality behind the various taboos have led him to argue (i) that respect for individual lives, for personal faith and personal autonomy, is widespread among ordinary people, probably a majority, in the USA and other Western democracies, but (ii) that such respect is, by contrast, minimal among the politicized authorities and professional associations of the same countries, governed, he says, by a mixture of economic incentives, bureaucratic inertia, and fear of vociferous minorities powered by hypercredulous belief and hence disproportionately influential.[193] One bizarre and tragic result is that prisoners facing the death penalty who petition the authorities to have their organs used to save other lives — and lives would unquestionably be saved because usable organs are scarce — have such petitions routinely and repeatedly refused. Some historical details are available on `http://www.rights.org/deathnet/Kevorkian_one.html` and more recent updates [April 1999] are in `http://www.interlife.org/kevorkian/` (The Kevorkian Papers, an anti-Kevorkian web site) and in `http://www2.privatei.com/hemlock/` (The Hemlock Society, arguing for the right to die with dignity).

192*a*. *Note added April 1999:* On 17 September 1998, Kevorkian, at the request of a paralyzed or near-paralyzed terminal patient, Thomas Youk, administered a lethal injection. A videotape of this (showing the patient asking to die) was broadcast on CBS TV on 22 November 1998. I think the humanitarian case was clear (for updates see `http://www2.privatei.com/hemlock/societyindex.html` and associated links), though I can no longer assert that Kevorkian 'never' himself took fatal action. My main point still holds: he was called a murderer long before 17 September 1998. Furthermore I would maintain, as do many others (including the Dutch Government, with strong popular support) that voluntary euthanasia is not murder. The word 'voluntary' is crucial, of course, meaning that the patient while in sound mind asks to die.

193. On this and on capital punishment, *see* `http://www.rights.org/deathnet/USnews_9703.html`, from which I obtained last year a summary of an interview published in the *Detroit News* of 3 March 1997 with 'top officials from Right to Life of Michigan, a large and powerful lobbying group' in Kevorkian's[192] home state. This lobbying group not only campaigns against assisted suicide but also has many members — as many as 50%, by the officials' estimates — who approve of the death penalty. Such approval was put forward, by the same officials, as justifying the group's decision — contradicting its own name, 'Right to Life' — to condone a move to repeal Michigan's 'present [as of March 1997] constitutional ban on capital punishment'. For more recent updates [April 1999], see e.g. `http://www.interlife.org/kevorkian/` (The Kevorkian Papers, an anti-Kevorkian web site) `http://www2.privatei.com/hemlock/` (The Hemlock Society, arguing for the right to die with dignity).

194. Ref. 135 (pp. 112ff., pp. 381ff.) describes and documents the witch mania launched by the Papal Bull of 1484. The basic procedure was to induce self-incrimination through torture of a victim selected almost at random, a state of things made possible by hypercredulous belief. Such belief was a phenomenon clearly recognized by whistleblowers such as Ady and von Spee,[165] e.g. 'No longer God or Nature, but witches are responsible for everything ...' (from an extensive translated quotation from von Spee in Chap. 24, pp. 382ff.). The situation was worsened by a system of financial incentives functionally equivalent to some of today's 'performance indicators' — tied to numbers of convictions, discounting the question of whether convictions were safe — and the incentives drove an exponential growth in the number of convictions. In more recent times, the best known examples include the McCarthyism in the USA of the 1950s — 'communists' being responsible for everything — and, with apt irony, the Cultural Revolution in communist China in the mid-1960s. This last is documented through eyewitness accounts in, for instance, David Hinton's BAFTA (British Academy of Film and Television Arts) Award winning television documentary 'Children of the Revolution'. The witch hunting process becomes self limiting when too many of the hunters become the hunted, but only after terrible devastation. David Hinton's film contains moving scenes of remorse in later years.

195. T. Keneally: 'Schindler has much to tell us', *The Times*, 22 March 1994, 20. Thomas Keneally's suggestion that 'people discover race hatred the way lovers discover love ...', seems to put its finger on the essential phenomenon and to describe what is repeatedly observed within many cultures. Keneally describes himself as 'an Australian of Irish Catholic background', and is the author of the book 'Schindler's list', also known as 'Schindler's ark'.

196. To defend the belief in Market Forces as the Answer to Everything one would have to defend their role, for instance, in suppressing accurate journalism,[247,253] in accelerating the spread and evolution of known serious diseases,[132,276,288] in launching *new* diseases,[138,139,249,270] in impeding rational approaches to

population control,[131] in squandering resources and devastating the environment,[155] in choking off long term investment in national infrastructure, including scientific capability,[244] in closing off the frequency windows for radio astronomy and Earth observation (e.g. *Nature*, 1998, **394**, 607), and in building the immense power of organized crime in general[289] and of the international drug trade in particular. Other examples, among many, include the role of market forces in the spread of medieval witch hunting.[194] Please don't get me wrong: I agree with those who argue that market forces can, in suitable circumstances, be a good thing.[155,156] It is the belief or feeling that they are the Answer to Everything — a belief that is often unspoken, but well illustrated for instance by Ref. 245 — that is dangerous.

197. R. Fears, M. W. J. Ferguson, W. Stewart, and G. Poste: 'Life-sciences R & D, national prosperity, and industrial competitiveness', *Science*, 1997, **276**, 759–760. This well illustrates the threat to credible, independent science from unregulated commercial interests, essentially similar to the threat to credible, independent journalism.[253] One quote is sufficient: 'All scientists [*sic*] must [*sic*] be prepared to accept and, more usefully, propose productivity measures for invention and innovation.' (The text then refers to a booklet edited by J. Anderson and R. Fears: 'Valuing and evaluating: assessment of the value of R & D in creating national and corporate prosperity: a report on the second SmithKline Beecham Symposium'; 1996, Oxted, Surrey, UK, Cross & Associates, 25 pp.) 'Without such willingness, the scientific community will come to be seen by politicians and the public as wanting to escape public accountability. Performance needs to be defined in terms of the quality of ideas generated and selected, the scope and scale of eventual industrial adoption' (and in terms of no other criterion, not even the understanding of industrial hazards[247,276]). Note especially the tacit presumption that it is possible, in principle, to predefine numerical 'productivity measures' that in some relevant sense automatically measure 'invention and innovation' and 'quality of ideas'; and note also the use of the phrase 'public accountability'[198,199] to mean 'conformity with what private industry considers its requirements to be'.[244] If the authors' strictures were to be put into universal practice, as seems to be demanded by their phrase 'All scientists must ...' — *see* also Ref. 245 — then there would be no longer be significant numbers of independent scientists and there would no longer be credible, independent scientific opinion on any matter of public concern.

198. M. Strathern, 'Improving ratings': audit in the British University system, *Europ. Rev.*, 1997, **5**, 305–321. A thoughtful essay by a distinguished social anthropologist, discussing the audit culture and Goodhart's law that 'when a measure becomes a target, it ceases to be a good measure'. *See* also Ref. 94*b* and the next two Notes,[199,200] Notes 152 and 197, pp. G27, G31 of the 99th (1990–1) edition of Pears Cyclopaedia for the original form of Goodhart's law, and, for a much broader perspective, K. Hoskin: 'The "awful idea of accountability": inscribing people into the measurement of objects', in R. Munro and J. Mouritsen (eds.): 'Accountability: Power, ethos and the technologies of managing'; 1996, London, International Thomson Business Press, 265–282. This illustrates the very wide applicability of Goodhart's law, and provides an in-depth historical discussion of what 'accountable' has come to mean. According to my 1995 copy of the Concise Oxford Dictionary (COD), 'accountable' is still thought to mean 'responsible, required to account for one's conduct', though — hinting at some of the conflations — it also gives a second meaning, 'explicable, understandable'. But Hoskin shows that the unconscious conflations and self contradictions in what I called 'neoaccountability' — including the negation of responsibility — can be traced back about two centuries. So, as usual, new is not so new, though still a mere flash of evolutionary time. The whole thing appears to be related to the 'Enlightenment Fallacy' in its most extreme form,[318] the hypercredulous belief that human behaviour can be reduced to simple laws like Newton's laws of celestial mechanics.

199. G. Neave: 'On looking both ways at once: scrutinies of the private life of higher education', *Europ. Rev.*, 1997, **5**, 305–321. This takes a puckish pan-European view of what is happening to university systems, acknowledging cross-national heterogeneities but also mincing no words about the ironies, and limitless cost, of replacing trust and reponsibility by 'mutual recrimination' and limitless pseudoaccountability (main text above, and Ref. 198). One consequence is that 'very few university management models have been tried and weighed in the balance before being put into place'. Our failure, so far, to cope with the hypercredulous aspects of the audit culture has put us, in nautical language, 'at sea with our sails all ahoo and our sheets a-drabble.'

There is perhaps no better example of sheets a-drabble than the recent promotion of the UK polytechnics to 'new universities', by political decree, followed by the Gadarene drive — literally suicidal in a globally competitive market — to try to make all university degrees equivalent through the audit culture: *see* J. Midwinter: 'Quality education in a mass market', *Science and Public Affairs* (London, Roy. Soc.), Autumn 1998, 22–25. The author estimates, incidentally, that 'about 80 shelf-feet' of paper had to be produced for the last audit of his Department's teaching.

200. A major news feature in the 11 September 1997 issue of *Nature*, **389**, 113–115, reports that the

belief in publication counting, and impact factor counting, is now taking hold in the Asian Pacific Rim countries and causing vast confusion: one physics professor is quoted as directly conflating quality with quantity: 'Without enough quantity [*sic*] as a base [*sic*], high academic quality can rarely if ever be achieved.' This is building the Taj Mahal by dumping rubbish.

201. F. Conway and J. Siegelman: 'Snapping'; 1978, New York, Lippincott, 254 pp. Valuable for its case studies of personal experiences in the American fundamentalist cults, and in other organizations exploiting what I am calling the hypercredulity instinct.[148] For more recent information, *see* for instance the book by Steven Hassan,[202] a former high-ranking official in the Unification Church (Moonies):

202. S. Hassan: 'Combatting cult mind control'; 1990, Wellingborough, Aquarian, 226 pp. First published in 1988. Since the publication of Ref. 201, there has been an important move to replace the old, partly coercive technique of 'deprogramming' by the strictly non-coercive exit counselling, or 'exit counseling' as it is spelt in US publications and, for the most part, in Internet search engines.

203. I agree with those who think the sacred can be rediscovered in ways that can be authentic in our time, in ways that do not coerce others. Within a vast literature *see*, e.g., Refs. 204, 259, 273–282. Also `http://www.tuxedo.org/~esr/writings/dancing.html` for a personal testimony, from a clear and highly articulate thinker (and lucid writer), Eric S. Raymond, about intense and healthy mystical, or visionary, experience and its ability to coexist perfectly easily with respect for the scientific ideal. He also claims that 'primary mystical experiences like mine are common' — something that scientists who happen not to have had them should consider. Raymond is also a well known practitioner, creator, and advocate of open-source software.[304a]

204. S. Kauffman: 'At home in the Universe: the search for laws of self-organization and complexity'; 1995, New York and London, Viking Penguin, 321 pp. Also Notes 1–4 and 71 of Part I. Kauffman provides cogent reasons why a deeper understanding of, and respect for, the nature of biological systems can be hoped for in the near future, along with many practical spinoffs, unforeseen until recently, such as entirely new weapons against the new disease epidemics. It is a question of putting hypermassive parallelism to work to solve combinatorially large problems, perhaps the beginnings of being able, one day, to beat disease agents at their own game.

205. It is instructive to contemplate what would be involved in simulating not the human brain, nor even an earthworm's brain,[290] but one of the much simpler (prokaryotic) single-celled organisms called bacteria. Even this is, as yet, hopelessly beyond the reach of our most powerful electronic computers (Note 284 below), as well as hopelessly beyond our detailed understanding of genetic function and evolution. The achievement and successful crosschecking of such a computer simulation against the behaviour of real bacteria would be an enormous scientific advance, were it to be achieved one day, and no doubt helpful in the race against antibiotic-resistant bacteria. That race is currently being lost[132,276] despite the emergence of new basic knowledge that should lead to fundamentally more powerful antibacterial weapons — using techniques that, ironically, solve combinatorially large problems by *molecular-biological* rather than by electronic means.[204,291] Such considerations belie the oft repeated idea that computers will soon outstrip the human brain in every respect, an idea repeated, for instance, in Ref. 70 of Part I.

206. S. J. Gould: 'Bright star among billions', *Science*, 1997, **275**, 599. Like Ref. 224, this *Science* editorial, paying tribute to the late Carl Sagan,[135] includes an eloquent and perfectly apt use of the words 'true', 'real', and 'provable', in the scientist's shorthand sense discussed in the main text above: '... for all his pizzazz and charisma, Carl always spoke for true science against the plethora of irrationalisms that surround us. He conveyed one consistent message: Real science is so ... exciting, transforming, and provable, why would anyone prefer the undocumentable nonsense of astrology, alien abductions, and so forth?' Stephen Jay Gould, who is Alexander Agassiz Professor of Zoology at Harvard University, also uses the editorial to comment on the 'narrow-minded error', on the part of some scientists, of 'equating popularization with trivialization, cheapening, or inaccuracy', and of downgrading 'the professional reputation of colleagues who can convey the power and beauty of science to the hearts and minds of a fascinated, if generally uninformed, public.' I agree with Gould that, on the contrary, we should remember the seriousness of the crises in public understanding and democracy, and give far more recognition to scientists like Sagan who succeed in the difficult art of clear and accurate 'popularization' — which can also, at the same time, be a significant aid to interdisciplinary communication among professional scientists working in different specialist fields, whether they admit it or not.

207. One clear example, among those I have seen for myself, was the series 'Heretic' (BBC2 Television, Tuesdays, July–August 1994). By not allowing discussion between experts and cranks, but presenting them as separate but equal, with no opportunity to point out inconsistencies — logically equivalent to $2 + 2 = 5$, even if harder to spot[136] — this grossly and dangerously misrepresented the nature, scope, and limitations of science. Further examples of crankish attitudes to science, conflating opinion and speculation with well checked knowledge, have even been appearing from time to time in influential and

widely circulated newspapers and magazines; *see*, for instance, Refs. 241 and 257 and the comments and references in *Nature*, 1994, **370**, 584, *Nature*, 1994, **373**, 90. There are signs, however, that parts of the newsmedia are becoming appropriately concerned,[247] and reasons to hope that this concern will grow.[263]

208. Quoted by A. Pais: 'Subtle is the Lord'; 1982, Oxford, University Press, 552 pp., p. 468. From Einstein's last autobiographical sketch, published in C. Seelig (ed.): 'Helle Zeit, Dunkle Zeit' 1956, Zürich, Europa Verlag.

209. E.g. K. Gottfried and K. G. Wilson: 'Science as a cultural construct', *Nature*, 1997, **386**, 545–547. Gottfried and Wilson give a scientist's view of what is sometimes called the Edinburgh 'strong programme' in the sociology of scientific knowledge (SSK), as illustrated for example in the influential book by ex-physicist Andrew Pickering: 'Constructing quarks'; 1984, Edinburgh, University Press, 468 pp. Though substantial and, according to Gottfried and Wilson, 'well informed', this book tends to convey, to a non-specialist reader, the notion of 'Science as Mere Opinion'. The resulting correspondence, in *Nature*, 1997, **387**, 543–546, **388**, 13, and **389**, 538ff., gives Pickering's replies plus some clear and specific examples of goodness of fit, the aspect of science often ignored or downplayed in the sociological studies; *see* also Fig. 3 above.

210. A. J. Leggett: 'The problems of physics'; 1987, Oxford, Oxford University Press, 192 pp. Page 20 mentions a lecture given by Lord Kelvin in 1900, in the course of describing late nineteenth century attitudes — '... how unthinkable the idea that their whole conceptual framework might be in error ...' *See* also Ref. 265.

211. The quantum–gravitational inconsistency implicit for instance in standard quantum electrodynamics (QED), is well known. To put it more sharply than usual, QED is like the 'elephant not identical to itself' shown in Fig. 4 of Part I: it implicitly says that electrons feel gravity yet do not feel gravity. The electron is treated as point like, and therefore as lacking structure at the Planck scale $\sqrt{(G\hbar/c^3)} \sim 10^{-33}$centimetre, where G is the universal gravitational constant, $\hbar$ is Planck's constant, and c is the speed of light. The search for ways round the associated difficulties is still fraught with great uncertainty and controversy; for further comments *see* Ref. 265, also `lucidity.ps` (Note 231d) on the Internet.[277]

212. The quotation in the main text is from p. 194 of Bell's collection of essays on quantum mechanics, Ref. 146. More fully: 'It is easy to understand the attraction' [of 'quantum philosophy'] '... for journalists, trying to hold the attention of the man in the street. The opposite of a truth is also a truth! Scientists say that matter is not possible without mind! All possible worlds are actual worlds! Wow!' On the many worlds hypothesis, *see* also pp. 136–137 and 189–195, and Ref. 213. On von Neumann's theorem and the first 'sharp quantum theory', the pilot wave theory of de Broglie and Bohm, *see* pp. 159–168, also e.g., for a recent contribution, Ref. 220. The pilot wave theory will probably be superseded, but it is enough in itself to disprove the conclusion traditionally drawn from von Neumann's theorem, that adding to quantum principles — traditionally but misleadingly called 'introducing hidden variables' — is impossible. Bell's lucid and penetrating arguments show more generally that quantum phenomena do not force us into any 'quantum philosophy' that renounces the scientific ideal of strict coherence and self consistency. Phenomena of 'quantum non-locality' or 'entanglement' may well force us — a point underlined by the famous Aspect *et al.* experiments on such non-local phenomena, e.g. the so called EPRB (Einstein–Podolsky–Rosen–Bohm) phenomena[216] — either toward a revision of one of Einstein's relativity principles (to say that 'no *information carrying* effect can propagate faster than the speed of light in a vacuum'), or toward some other drastic revision, of our ideas about spacetime for instance,[149] or about the algorithmic computability of physical theories.[149,226] Here 'information' means readable information and not information about quantum states, a point underlined by the recent experiments on 'quantum teleportation'.[292,293,310] Our understanding is, indeed, shaky and incomplete.[265]

213. A. Kent: 'Against many-worlds interpretations', *Int. J. Modern Phys.*, 1990, **A 5**, 1745–1762. This usefully and cogently supplements Bell's classic discussion[212] 'Quantum mechanics for cosmologists', with more technical detail. For the latest experimental checks on Bell's inequalities and EPRB (Einstein–Podolsky–Rosen–Bohm) effects, *see* Refs. 292, 293.

214. D. Bohm: 'On Bohr's view concerning the quantum theory', in 'Quantum theory and beyond', (ed. T. Bastin), 33–40; 1971, Cambridge, Cambridge University Press, 345 pp. More detailed comments in Note 50 of Part I.

215. S. Goldstein: 'A theorist ignored [review of a recent biography of David Bohm.[219]]', *Science*, 1997, **275**, 1893–1894, and other papers at `http://math.rutgers.edu/~oldstein`. Also S. Goldstein: 'Quantum philosophy: the flight from reason in science', in 'The flight from science and reason', (ed. P. R. Gross, N. Levitt, and M. W. Lewis), *Ann. N.Y. Acad. Sci.*, 1996, **775**, and other papers at `http://math.rutgers.edu/~oldstein`.

216. N. D. Mermin: 'Is the moon there when nobody looks? Reality and the quantum theory', *Phys. Today*, 1985, **38**(4), 38–47. A lucid and cogent discussion of the original example of quantum nonlocality, called Einstein–Podolsky–Rosen–Bohm correlation; *see* reference to Einstein's relativity in Note 212. For more recent developments, *see* for instance Refs. 292, 293.

217. This vagueness is well brought out in M. Gell-Mann: 'The quark and the jaguar: adventures in the simple and the complex'; 1994, New York, Freeman; London, Little Brown, 392pp. *See* the section 'Measurement situations and measurements' and the first half of the following section, i.e., pp. 154–155, and note for instance, regarding fission tracks in 'rocks that are hundreds of thousands of years old', the statement that, according to the standard principles of quantum mechanics, 'the actual measurement could have been carried out by a cockroach or any other complex adaptive system. It consists of "noticing" that a particular alternative has occurred ...' (p. 154). There is no explicit description of how, why, or in what sense the cockroach could have 'noticed' the fission track, nor discussion of the implications for radioactive decay of rocks on lifeless planets or for nuclear reactions within the Sun.

218. D. Bohm: 'On the role of hidden variables in the fundamental structure of physics', in 'Quantum theory and beyond', (ed. T. Bastin), 95–116; Cambridge, Cambridge University Press, 345 pp.

219. F. D. Peat: 'Infinite potential: the life and times of David Bohm'; 1996, Reading, MA, Addison-Wesley, 353 pp. Reviewed in *Nature*, 1997, **385**, 592 by Chris Philippidis, in *Science*[215] by Sheldon Goldstein, and in *Physics Today*, 1997, bf 50(3), 77-78 by James T. Cushing: '... this book does make a prima facie case for Bohm as a fascinating and important scientist ... But it probably has not given David Bohm his due.'

220. T. M. Samols: 'A stochastic model of quantum field theory', *J. Statist. Phys.*, 1995, **80**, 793–809. 'To a realist, ... a space of objectively defined events must be restored to the theory.' The model is discrete ('light-cone lattice theory'), and there is no claim to have overcome the difficulty of going to the continuous limit. 'One may think of the model as simply ... [the Bell–Everett theory] ... but with its two defects — absence of sensible histories and frame-dependence — simultaneously cured.'

221. F. Dowker and A. Kent: 'On the consistent histories approach to quantum mechanics', *J. Statist. Phys.*, 1996, **82**, 1575–1646. This admirably lucid paper contributes to the debate about quantum mechanics and its domain of applicability. Note incidentally that the word 'consistent' in the title is short for 'probability-consistent', a specialist technical meaning that differs from the standard logical meaning, freedom from contradiction, used in my discussion. Roughly speaking, the 'consistent histories' approach, also called the 'decoherent histories' approach, is an attempt to force the (Everett) many worlds theory into a single world. It has not yet become a quantitatively precise model. *Additional note:* In 1996 I had a chance to ask Murray Gell-Mann, one of the eminent physicists advocating the consistent histories approach, a basic question to check on the last point. The occasion was question time after his lecture to a geophysics conference at the Hotel Santa Fe, New Mexico, on Wednesday 19 June 1996. I asked whether any explicit predictions had been made for the timescale or timescales of the quantum mechanical branch-pruning events that are hypothesized to replace what is usually called the collapse of the wavefunction (Ref. 217, p. 156). The answer was to the effect that there is, as yet, no definite prediction: the timescale will 'depend on the parameters of the problem.' Adrian Kent, our local expert on these matters,[213,221] tells me that, to his knowledge, the position has not changed as this goes to press.

222. There have always been, of course, in storytelling from time immemorial,[179] suggestions of other worlds nearly or completely isolated from ours; and for versions consistent with known physics *see* Ref. 224 and L. Smolin: 'The life of the cosmos'; 1997, London, Weidenfeld and Nicolson, 358 pp. Other worlds in this sense pose no problems for objectivity and experimental repeatability. It still makes sense to talk about the outside world, for those purposes, meaning whatever world or universe is observable by us. This is an entirely different matter from the superposed worlds of the quantum many worlds hypothesis. Further notes are on the Internet[277] (Notes 293 and 293a of `lucidity.ps`).

223. D. J. Fixsen, E. S. Cheng, J. M. Gales, J. C. Mather, R. A. Shafer, and E. L. Wright: 'The cosmic microwave background spectrum from the full COBE FIRAS data set'; 1996, *Astrophys. J.*, **473**, 576–587. This is the paper from which Fig. 3 above is taken. COBE stands for 'cosmic background explorer', and FIRAS for 'far infrared absolute spectrophotometer', where 'absolute' has its technical experimental meaning, that measured values contain no undetermined additive constant: there is no freedom to shift the points plotted in Fig. 3 up or down relative to the scale at the left. It is difficult to imagine the vast effort involved in conceiving, designing, building, using, and crosschecking the exquisitely precise yet robust instrumentation that made these measurements possible, from a spacecraft bombarded by high temperature photons and other particles from the Sun, and by cosmic rays. Such considerations, and the paper itself — if you have the patience to follow its closely argued detail — gives some inkling, at a level accessible to a physics or chemistry undergraduate, of what may be involved in trying to approach

the 'scientific ideal one of whose demands is that the whole edifice of experiment and theory should be self consistent', as discussed in Parts I and II. There is nothing in the paper about absolute truths or final answers. *See* also the excellent popular account of the whole COBE mission by J. C. Mather and J. Boslough: 'The very first light: the true inside story of the scientific journey back to the dawn of the Universe'; 1996, London, BasicBooks, 328pp. Also London, Penguin, 1998, 328pp.

224. M. J. Rees: 'Before the beginning: our Universe and others'; 1997, London, Simon and Schuster, 282 pp. One of today's most respected scientists discusses, with great insight and lucidity — and marvellous succinctness — what we know, what we do not know, and what it might be well to know, about the world we live in especially in its smallest and largest scale aspects. Any thoughtful person reading this book will see why giving up the pursuit of such knowledge would be a dangerously head-in-sand attitude. The book also shows, perhaps more clearly than any other I have read, how to use the working scientist's shorthand terms 'knowledge', 'proof', 'decisive evidence', 'fact', 'truth', etc., in plain, simple, and apt ways that respect the scientific ideal and that distance themselves from hypercredulous belief. Indeed it well illustrates what respect for the scientific ideal means in practice: both the astonishing power to advance our understanding of the outside world through experiment, observation, and appropriate theorizing or model-fitting, and also, equally, the implied respect for the limitations of science, and the humility in the face of the unknown.

225. I. C. Percival: 'Quantum spacetime fluctuations and primary state diffusion', *Proc. R. Soc. Lond.*, 1995, **A 451**, 503–513.

226. T. N. Palmer: 'A local deterministic model of quantum spin measurement', *Proc. R. Soc. London*, 1995, **A 451**, 585–608. The idea is to replace quantum non-locality by algorithmic non-computability arising from 'riddled basins' of attractors in phase space. For an excellent lay person's description *see* Ref. 186, 2nd edn, pp. 348–356.

227. J. L. Casti: 'Paradigms lost'; 1989, London, Little, Brown, 567 pp. This massive but entertaining book takes us on a romp through many of the fashionable philosophical debates and is useful for getting a quick idea of what the fuss is about. It vividly shows the dichotomization instinct at work.

228. A. F. Chalmers: 'What is this thing called science? An assessment of the nature and status of science and its methods'; 2nd edn; 1982, Milton Keynes, UK, Open University Press, 179 pp. This book gives a useful quick introduction to recent thinking among historians and philosophers of science, carrying on from naive inductivism to Popper, Lakatos, Kuhn, and Feyerabend. In Chalmers' own admirably honest words, 'We start off confused and end up confused on a higher level' (p. xix).

229. B. Russell: 'History of Western philosophy and its connection with political and social circumstances from the earliest times to the present day', 2nd edn; 1961, London, Routledge, 842 pp. An incisive single-volume summary of 'the celebrated intellectual struggles of the great philosophers', all the way from the Ancient Greeks to the early twentieth century, though out of date on Nietzsche.[230,283] Referring to 'philosophies' in the sense of theories of knowledge, Russell remarks on p. 592 that, at the time of writing, 'No one has yet succeeded in inventing a philosophy at once credible and self-consistent.' On the origin of 'instrumentalism' *see* pp. 775ff., also, however, Ref. 230, p. 293. For current fashions as to what 'instrumentalism' means — and the term seems to have fallen victim to dichotomization, the emphasis on model-fitting while seeming to ignore the reality to which models are fitted — *see* for instance Refs. 147, 150, 227, 228, and 297.

230. B. Magee: 'The great Western philosophers'; 1987, Oxford, University Press, 352 pp. This gives an excellent introduction to the classical philosophical background, in the form of an unusually clear, wide-ranging, and accessible discussion, more up to date than Ref. 229. On Nietzsche, see also the remarks in Note 283.

231. One striking and well-checked example — *see* also Refs. 174 and 204 — is the mitochondrial protein molecule, more accurately molecule assembly, H^+-ATP synthase. It or its subunits are also variously referred to as F_1-F_0-ATPase and F_1-ATPase, depending on which aspect of its functioning is being emphasized. It is about 10 nanometres in diameter and is made of around 10^5 atoms. It functions as a rotary dynamo or motor, with one subunit rotating continuously with respect to another. The rotary action was first deduced from indirect lines of evidence and subsequently made visible through a microscope, in a recent experiment giving a beautiful consistency check on the whole picture: H. Noji, R Yasuda, M Yoshida, and K. Kinosita: Direct observation of the rotation of F_1-ATPase', *Nature*, 1997, **386**, 299–302 (also *Nature*, 1998, **394**, 324–325). In the mode of functioning used in the experiment, the power source for the rotation was the 'fuel' ATP (adenosine triphosphate) that powers most cell processes. The normal functioning is in the opposite sense, not consuming but manufacturing ATP as fuel to sustain the rest of the cell. The manufacture of ATP draws on a kind of electric power source in which the 'pulling power of free oxygen' sustains a counterflow of electrons and protons through H^+-ATP synthase molecules embedded in mitochondrial inner membranes (Ref. 161, p. 19; also, e.g.,

commentary by S. M. Block: *Nature*, 1997, **386**, 217–219). When functioning in this mode, H^+-ATP synthase (strictly speaking the F_0 subunit) could be called the world's smallest electric motor. Gimzewski et al,

232. Take for instance, among countless examples, the attempt to confuse the US National Academy of Science's draft document on standards of science teaching in schools (*Science*, 1994, **265**, 1648–1650; *Nature*, 1995, **375**, 439; *Nature*, 1995, **378**, 528), and the advocacy of extreme cultural relativist views in a major BBC television documentary, 'The Far Side' (Horizon/WGBH, 30th Anniversary, BBC2 Television, 23 May 1994). These views reasonably say that scientific theories are constructed by humans, but unreasonably ignore goodness of fit and the power of Occam's razor,[209] as illustrated by Fig. 3 above — seeming to say, with Jonathan Livingstone Seagull, that what happens when you step off a tenth storey window ledge is purely a matter of culture or opinion. That a team of high powered professional journalists, to say nothing of some professional educators, could so confuse fantasy and reality was to me a profound shock, especially after having seen many excellent, coherent and well informed science documentaries in the Horizon/WGBH series; and it is plain from the burgeoning literature that many other scientists have been similarly shocked; e.g. Ref. 236. Unfortunately, however, the resulting situation looks more and more like tribal conflict, and has come to be referred to as the 'science wars'. As usual — and it bears repeating — we have a false dichotomy: 'Science as Mere Opinion' versus 'Science as Absolute Truth'. The test for scientists is now whether they, or rather we, will be collectively smart enough to see the falseness of both sides of the dichotomy and find a lateral way out.[235]

233. That the unconscious drive to prune trees of possibilities is an inevitable part of how perception and cognition work was argued, I hope convincingly, in Parts I and II. It is a way of coping with the combinatorial largeness, already emphasized, of such trees of possibilities.

234. H. Belloc: Sonnet 31 of 'Sonnets and verse' (posthumous collection); 1954, London, Duckworth, 183 pp., republished 1978. It was first published in 1938 and is given the date 1938 in the Oxford Dictionary of Quotations, 4th edn. The next sonnet touches a similar chord: '... For all believing's but a dance of shades.' Belloc (1870–1953) was a professing Roman Catholic Christian, a humanist and a polemicist for civilized values, and an astute observer of human nature and of 'things as they are'. He seems to have tried hard to clarify what I am calling the distinction between personal faith and hypercredulous belief.

235. For a quick perspective on 'science wars' I would recommend the editorial 'Science Wars and the need for respect and rigour' (*Nature*, 30 Jan. 1997, **385**, 373), and the 'Science Wars Briefing' in *Nature*, 1997, **387**, 331–335. Also e.g. S. S. Schweber: 'Reflections on the Sokal Affair: what is at stake?', *Physics Today*, March 1997, **50**(3), 73–74, and M. Beller: 'The Sokal hoax: at whom are we laughing?', *Physics Today*, September 1998, **51**(9), 29–34. The challenge now facing everyone of good will is to contribute seriously to the discussion, as these essays try to, with the utmost care over professional standards of argument, and in particular for scientists to understand the origins and valid aspects of the cultural relativist and social constructivist perceptions — not only because some of those perceptions are indeed valid, as many scientists have long realized,[190,287] but also because some of them are, in any case, shared by journalists[232] and by people with responsibility in high places, and may well continue to be politically influential through the newsmedia for instance.[232] And such perceptions are playing 'a key role in debates about the public perception of science related risks'.[266–268] Good examples of high quality discussion are being quietly set here and there; *see* e.g. the thoughtful and reconcilatory discussions in Refs. 137. Further relevant discussion situation may be found for instance in Refs. 143, 145, 160, 167, 209, 224 (briefly and quietly), and 228, 236, 275, and 294. I found the last chapter of Ref. 167 particularly helpful in getting over my own first shocked reaction, which was exactly that recorded in Ref. 236:

236. P. R. Gross and N. Levitt: 'Higher superstition: the academic left and its quarrels with science'; 1994, Baltimore, MD, Johns Hopkins University Press, 314 pp. This typifies the scientists' side, understandable in many ways,[232] of the polarized 'science wars' literature. An earlier shot was fired by T. Theocharis and M. Psimopoulos: 'Where science has gone wrong', *Nature*, 1987, **329**, 595–598, indiscriminately demonizing Popper, Lakatos, Kuhn, and Feyerabend equally as 'betrayers of the truth' and caricaturing, in particular, what seems to me to be careful and perceptive thinking by Popper.

237. E. Tenner: 'Why things bite back: technology and the revenge effect'; 1996, London, Fourth Estate, 346 pp. A thoughtful discussion of the unexpected side effects of new technologies: 'Whatever happened to the paperless office?' and so on, to say nothing of antibiotic resistance.[132,276] *See* also *Science*, 1997, **275**, 41, suggesting that the asthma epidemic may be a revenge effect, perhaps from the battle against tuberculosis.

238. J. Maddox: 'Valediction from an old hand', *Nature*, 1995, **378**, 521–523. Looking back on his experience as editor of *Nature* during 1966–73 and 1980–1995, John Maddox puts it perfectly: 'there

can be no more important goal for the research community ... than to cut the link between publications and success' (creating, as it does, such a strong incentive to corner cutting and even to outright scientific misconduct,[239] that is, to gross violation of the scientific ethic). Maddox cites his own experience of the 1980s. He also lists some of the major advances in hardcore scientific knowledge that took place in the 1980s, despite human lapses. On the insoluble, ethic-damaging, and bureaucratically amplified problem of who should be first, second, third, ... author, *see Nature*, 1997, **388**, 320 for an excellent defence of alphabetical order as the normal practice, and what to do about young scientists' career advancement through means other than first authorship. *See* also the editorial in *Nature*, 1997, **387**, 831, stressing the 'hyper-collaborative' nature of most of today's significant research, and 1997, **388**, 14 and 511 for the statistical controversy over 'Aabel's Advantage'. These are among the most important reasons for questioning the audit culture.[198,248]

239. W. H. James: 'Fraud and hoaxes in science', *Nature*, 1995, **377**, 474–474. This gets fraud into perspective, making the point that — though, under today's pressures, fraud is inevitably an increasing problem — honest error in science is still 'far more common than outright fraud' — despite, a cynic could add, today's ever increasing market-style incentives[197,245] to fraud. There is also, still, the societal counterpressure, the knowledge that fraud still risks catastrophic destruction of a scientist's career — a counterpressure that exists mainly because professional peer review, with all its imperfections, is still in use despite the bureaucratic dream of replacing it by so called objective performance indicators.[194,197,198]

240. A. B. Pippard: 'Footnote to history', *Nature*, 1991, **350**, 29. Argues from the cold fusion debate that 'the institution of science is robust' — despite some very conspicuous human lapses.

241. For information about the commercial, legal and political battles involving scientific issues, *see* almost any issue of *Science* or *Nature* in the 1990s and, for instance, the Spring 1997 issue of *Science and Public Affairs*. Also, especially, Note 242. One battleground, global environmental change, where I have some specialist knowledge of my own, can be glimpsed through Ref. 247 and independently through the news items and correspondence in, for instance, *Nature*, 1996, **381**, 639, **382**, 665, and 1997, **386**, 131–133, 164–167. On the scientific uncertainties about global environmental change, including sea-level change, *see* e.g. the recent book by Schneider[257] as well as the 1995–96 IPCC report.[256] I agree with Schneider's remarks on p. 156 about the 'conflict, frenzy and distortion' resulting from conflation, by the newsmedia and others, of scientific with commercial, legal and political questions, and further complicated by the espousal of scientific crankishness by the newsmedia.[207,253] I also agree with him about (i) the very high uncertainty in our present conceptual and numerical models of global environmental change, (ii) the possibly serious and potentially catastrophic consequences of such change, and (iii) the 'outrageous' yet widely reported public claims by a few scientists that (p. 154) 'their special knowledge of the future allows them to know with high certainty something virtually everybody else in the expert community disputes: that the probability of any non-negligible outcomes' of anthropogenic global change 'is virtually zero'. This again is the driver on the foggy road 'who shuts his eyes and blocks his ears and claims infallible prior knowledge' of what lies ahead. Cases of powerful newsmedia support for such irresponsibility are documented in Ref. 247 and in S. K. Avery, P. D. Try, R. A. Anthes, and R. E. Hallgren: 'An open letter to Ben Santer', *Bulletin of the American Meteorological Society*, Sept. 1996, **77**, 1961–1966. *See* also Note 258.

242. Take for instance the legal battle to get the USA's Academy Complex (the National Academy of Sciences, the National Academy of Engineering, the Institute of Medicine, and the National Research Council) legally recognized as independent, and not as a federal government agency subject to the FACA (Federal Advisory Committee Act) and its so called 'sunshine laws', one of which requires all committee meetings, no matter how technically abstruse the subject matter and no matter how tangled the web of uncertainties, to be held in public under civil service supervision, with all political interests and pressure groups represented. *See*, e.g., *Nature*, 1997, **387**, 746, **387**, 220, **386**, 309, **385**, 755, and **386**, 525, the last being an editorial defending the 'track record of the academy ... in producing studies that the nation can trust', a track record that distances such studies, by a distinct 'credibility gap', from studies by government agency committees subject to FACA hence subject to the full pressures of commercial and other vested interests.[244] The Congressional hearings reported in Chap. 3 of Ref. 247, pp. 63ff., are enough to illustrate what can happen when institutions fail to recognize that 'science and politics don't mix' (even though they must increasingly live together[305]). The BSE affair[270] and the resulting wealth destruction in the UK underlines the same point: it was clear from the outset, to anyone aware of the scientific uncertainties about spongiform encephalopathies, that respect for the scientific ideal was needed — not least humility in the face of the unknown — but in the event political pressures gave these little chance. *Addendum:* Progress toward securing independence for the US Academy Complex through a special bill of Congress has been reported in *Nature*, 13 Nov. 1997, **390**, 104.

243. C. K. Gunsalus: 'Ethics: sending out the message', *Science*, 1997, **276**, 335. This editorial is one of

countless public statements by scientists that call attention to the importance of respect for the scientific ethic. It reminds us too that such respect will be in jeopardy unless university students, in particular, perceive their mentors as respecting the ethic, rather than being wholly driven by the commercial and other narrow forms of self interest that scientists are now under pressure to espouse. This in itself is a strong argument not to push too far the reliance on funding by commercial industry, or by research funding councils whose priorities are dictated by politics or commerce.

244. C. G. Kurland: 'Beating scientists into plowshares', *Science*, 1997, **276**, 761–762. Points out some of the devastating consequences to research and education, and, by implication, to other kinds of infrastructure, of unconstrained market forces, citing detailed documentation in the case of the author's field of molecular biology. The focus is on what are perhaps the most powerful identifiable market forces at work today, those associated with the private financial 'transaction sector', which deals with money alone,[253] whose timescale is that of the quarterly financial report and whose practitioners, including financial advisors, economists, and market analysts, consume a very substantial fraction of the world's total business turnover (J. J. Wallis and D. C. North: in 'Long term factors in American economic growth', (ed. S. L. Engerman and R. E. Gallman), 95–163; 1986, Chicago, IL, Chicago University Press, 95–163) — far greater than the resources of any present-day institution that is trying to think on longer timescales, including even the military. Kurland reminds us that forces of such magnitude pose, in particular, one of the gravest threats to the openness of academic research and hence, by implication, to the survival of the scientific ethic and the credibility of public statements by tomorrow's scientists. *See* also Refs. 197 and 245, to the first of which Kurland's article was in part a reply, and S. L. Pimm: 'The value of everything', *Nature*, 1997, **387**, 231–232. This points out that unconstrained market forces, being blind to 'overarching moral issues', would be likely, on their own, to ensure the reintroduction of, for instance, child labour where it is not already established, especially if the forces are those brought into play by the kind of opinion poll run by market analysts, reinforcing market-force hypercredulity by asking questions of the type 'What would you personally pay each year to prevent the reintroduction of child labour?'

245. T. Kealey: 'The economic laws of scientific research'; 1996, London, Macmillan/New York, St Martin's Press, 382 pp. More precisely, this book says, contradicting itself, that the market forces governing science (and everything else) should be regulated yet unregulated. Going beyond Ref. 197, it argues the case for, in effect, cancer research to be sponsored by the tobacco industry, food safety by the food, pesticide, and agricultural industries, environment by the fossil fuel industries,[247] and so on — without ever saying so. From the title onwards it skilfully positions the reader — manipulates unconscious prior probabilities[140] — to accept that there are such things as very simple, and inviolable, economic 'laws' of scientific research, and that there is a wholly 'virtuous' (pp. 239, 245), 'rational', and 'objective' (p. 260–261) entity variously called 'capitalism', 'the free market', 'free trade', and '*laissez faire*'. It is not the practitioners of such 'virtue', but rather people in government and, by implication, government funded scientists, that are 'greedy' and wish 'to acquire others' [*sic*] wealth' (e.g. p. 260). Any departure from such beliefs, such as a suspicion that some capitalists might themselves be greedy, is an 'error': Kealey cleverly avoids saying 'heresy' or 'sacrilege'. Colin Humphreys (*Europ. Rev.*, 1997, **5**, 443–445) has drawn attention to official OECD figures (Organization for Economic Cooperation and Development) that disprove Kealey's 'laws' that 'public and private funding displace each other' and that 'public funds displace more than they do themselves provide' (p. 245). There are other factual howlers — a large number of which are documented in ref. 302 — to which can be added the reference on p. 301 to a nonexistent yet 'emerging' OTA, the US Office of Technology Assessment, which far from 'emerging' was abolished by Congress in 1995 through what Ref. 247 (Chap. 3) calls 'a most wilful and determined ignorance', itself, apparently, an example of market-force hypercredulity, as Kealey's book itself plainly is. See for instance p. 344: '*Laissez faire* meets all [*sic*] needs.' I agree with Kealey on some points, especially that 'only a plurality of funding will feed a plurality of thought' (p. 185), that the public funding of science does not, of itself, guarantee either good science or ethical science, and that there is plenty wrong with the present day public funding of science. I would add that some of what is wrong stems from Goodhart's law[198] and the publication counting technique[248] — a technique extensively used in Kealey's book.

246. H. G. Danielmeyer: 'What industry expects from science', *Europ. Rev.* , 1997, **5**, 185–191. A brief and useful historical perspective on the relation between science and industry, and a sober assessment of current trends that every scientist should read and think about[260,261] — though like Refs. 197 and 245 it still seems to ignore society's need for a science base that is independent of commercial interests.

247. R. Gelbspan: 'The heat is on: the high stakes battle over Earth's threatened climate'; 1997, New York, Addison-Wesley, 278 pp. This book is a substantial and courageous piece of investigative journalism, documenting, so far as corporate secrecy permits, the politics and financing of, and newsmedia collaboration with, the fossil fuel industry's propaganda campaign on global environmental change aimed

at keeping the heads of the US public, Congress, and Senate firmly in the sand. The climate battle is a clear case of the scientific ideal and ethic, and scientists personally, coming under direct attack by short-term commercial interests wielding supranational economic power (for updates *see* also, e.g., *Nature*, 1997, **390**, 649 and 1998, **392**, 639, and P. N. Edwards and S. H. Schneider, 'Self-governance and peer review in science-for-policy: the case of the IPCC Second Assessment Report', *Publ. Und. Sci.*, submitted 1998.) Gelbspan's book includes transcripts from hearings of the US Congress, and important factual material (e.g. pp. 232–236) whose publication was suppressed by one of the major collaborating newspapers, the *Wall Street Journal*; further details of such suppression is documented in the publicly available article by Avery et al. referred to in Note 241. Although the book contains extensive quotations from testimonies by respected scientists, it is an intelligent lay person's view and does not itself purport to be scientifically definitive; in particular, I do not think it puts enough emphasis on the enormous uncertainties. For the scientific aspects *see*, rather, Notes 256–258. Gelbspan's book is particularly valuable, though, in documenting the little that is known publicly about the industry's payments to the tiny minority of scientists willing to suggest that fossil-fuel pollution is certain to be harmless or beneficial. The tobacco counterpart of this appears to be better documented; e.g. M. Wadman: 'Dilemma for journals over tobacco cash' *Nature*, 1998, **394**, 609, about '... last week's revelations that more than a dozen scientists received $156,000 from the tobacco industry to write letters and manuscripts disputing the carcinogenicity of second-hand smoke — a project to seed the literature with a particular point of view for a defined sum of money.' To my knowledge, most scientists would still agree with the journal editor who was 'appalled' by this.

248. P. Lachmann and J. Rowlinson: 'It's *what* not *where* you publish that matters', *Science and Public Affairs* (London, Roy. Soc.), Winter 1997, 8. The authors are, at the time of writing, the Biological and Physical Secretaries of the Royal Society of London, the UK's national science academy. They 'are firmly of the view that the practice of judging the quality of the work by the journal in which it is published not only corrupts the process of peer review but also promotes *a form of scientific misconduct*' [my emphasis]. 'The use of bibliometric analysis [including journal impact factors] for judging individual authors has promoted a publication culture where papers proliferate in number and results are published in increasingly small aliquots' [if only to give everyone a chance of first authorship, in accordance with Goodhart's law and some forms of bibliometric auditing] 'and where there is excessive citation of other papers, even where this is not frankly corrupt as in the formation of "citation rings" ... We strongly deprecate this practice ... We have as far as is in our power tried to prevent its use in the [UK universities' triennial] Research Assessment Exercise.' The latter, as far as I know, has indeed tended up until now to use a 'few best publications' system in which the onus is on the assessees, the authors, to judge and declare which few of their own publications are best, *in the knowledge that those publications might actually be read* by an expert assessor.

A more general shift from 'many worst' to 'few best' might yet meet legitimate auditing concerns, yet limit the damage being done to science by the present audit culture.[198,200]

249. Within a vast literature *see*, for instance, the *Nature* editorial of 27 March 1997 (**396**, 307) on 'short-termism,' both in private capital investment and in government management of the science base. UK government research funding of work in, for instance, problems like BSE[139,270] is described — *see* also Note 250 — as being 'switched on an off like a tap'.

250. T. Blundell: 'The Foresight Saga and other stories from the science budget', *Science and Public Affairs* (London, Roy. Soc.), Spring 1997, 2–4. This commentary is by an eminent scientist who was in a position of national responsibility (Head of the UK Biotechnology and Biological Sciences Research Council) at the time of a sudden research priority switch imposed from above, followed by even more sudden budget cuts imposed on the research councils and universities — sudden in the sense that their announcement broke previous promises and left little time to plan for damage limitation. The general picture of wastage by inept political interference is corroborated by much other anecdotal material, including my own personal experience on a policymaking committee of another UK research council, the Natural Environment Research Council.

251. R. Elliott: 'Threats to full and open access to scientific data', *ICSU Focus*, Autumn 1997, **10**, 3–4. Further information from Dr Peter Collins, Science Advice Section, The Royal Society, 6 Carlton House Terrace, London SW1Y 5AG, UK, tel. +44 171 451 2584). For an update on the growth of this threat, see e.g. a news item by Tony Reichhardt in *Nature*, 30 July 1998, **394**, 410, concerning the USA's Coble and Grams bills and the World Intellectual Property Organization.

252. A. Michaels, D. Malmquist, A. Knap, and A., Close: 'Climate science and insurance risk', *Nature*, 1997, **389**, 225–227. A well argued example of how open, credible science can benefit business, in this case the insurance and reinsurance business, with emphasis on the essential role of openness and peer review. *See* also Notes 158 and 247, and 303 on 'science roadmaps'.

253. M. Bell: 'The truth is our currency'. Four 15 minute radio talks, first broadcast on BBC Radio 4, 16 May to 6 June 1997, by Martin Bell, a BBC television war reporter widely respected for his integrity. Transcript available from BBC Videos for Education and Training, 80 Wood Lane, London W12 0TT, UK, fax +44-181-576-2916. The second talk, 'News and war', gave an inside view of what happened in the television reporting of the Gulf and Bosnian wars, and a carefully argued discussion of the implications, some of which are positive: '... in an age of satellite television, crimes against humanity are harder to commit, or at least to get away with, and will cultimately do most damage to those who commit them. The Bosnian conflict occurred at a point of intersection between warfare and news ...' But the third talk, 'News and money', pointed out how market forces, as interpreted by what Kurland[244] calls the private 'transaction sector' of international financial advisors, economists, and market analysts, are increasingly pressurizing journalists, even reputable international news agencies like Reuters, to do whatever sells newsmedia output regardless of anything else, even human life: '... if ... nothing matters but money ... then in that case news is only what you say it is. It is whatever sells newspapers or pulls in viewers ... Money knows no realities but its own.' This is also a good answer to the science marketeers.[197,245] If nothing matters but money, or numbers of publications, or other irrelevant measures of so called productivity,[152,194,198,199,239,248] then the results of an experiment are what you say they are — offering, too, the 'efficiency gain' of not having to do the experiment at all.

254. D. Kennedy: 'Academic duty'; 1997, Cambridge, MA, Harvard University Press, 310 pp, (ISBN 0 674 00222 9). A passionate and well informed plea for taking professional responsibility seriously, with emphasis on university teaching, the other side of the 'academic freedom' bargain.

255. E. F. Schumacher: 'Good work'; 1979, London, Cape, 148 pp. *See* Chap. 2 for the Gandhi quote about civilization being 'a good idea', and Chap. 4 for the 'third great illusion' of our time, the illusion that 'science can solve all problems', the first and second great illusions being that there is room for infinite exponential growth and that society has an infinite supply of mindless labour. The book describes some successful yet humane small business enterprises, some of them meeting third world needs. Schumacher also, in his best known book 'Small is beautiful: a study of economics as if people mattered' (1973), finds words that capture very well the phenomenon I am calling market-force hypercredulity: 'Call a thing immoral or ugly, soul-destroying or a degradation of man, a peril to the peace of the world or to the well-being of future generations: as long as you have not shown it to be "uneconomic" you have not really questioned its right to exist, grow, and prosper.'

256. J. T. Houghton, L. G. Meira Filho, B. A. Callander, N. Harris, A. Kattenberg, and K. Maskell (eds.): 'Climate change 1995: the science of climate change (Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change)'; 1996, New York and Cambridge, Cambridge University Press, 572pp. This major collective effort is an example of what are coming to be called science or technology 'roadmaps'.[303] Their emergence is an important example of human adaptability through organic cultural change, and an important demonstration of cooperation in the face of competition. For the essential points in the case of climate *see* also J. D. Mahlman: 'Uncertainties in projections of human-caused climate warming', *Science*, 1997, **278**, 1416–1417. This last is a brief but careful summary and update by a respected expert, with clear emphasis on the balance of probabilities. One big uncertainty, with big insurance implications, is whether tropical cyclones, ranking close to major earthquakes in terms of loss of life, will become significantly more intense; for an update by a respected research team *see* T. R. Knutson, R. E. Tuleya, and Y. Kurihara: 'Simulated increase of hurricane intensities in a CO_2-warmed climate', *Science*, 1998, **279**, 1018–1020. Predicted increases in wind speed are 5–12%, corresponding to a 10–25% increase in forces on trees and buildings.

257. S. H. Schneider: 'Laboratory Earth: the planetary gamble we can't afford to lose'; 1996, London, Weidenfeld and Nicolson/New York, HarperCollins (Science Masters series), 184 pp. This book by a professional climate researcher gives a clear and widely understandable discussion of the reasons for our large uncertainty about future environmental change — including what is simplistically called 'climate change' — and what its early warning signals might be, with some discussion of the current politics. There are straightforward uncertainties, for instance, about the numerical magnitudes of some critical parameters, concerning cloud droplet sizes for instance, and the rates and modes of transport of water, carbon dioxide and other chemicals and pollutants in the atmosphere–ocean–cryosphere–biosphere system and the concomitant biological adaptations.[138] Another, more subtle reason for uncertainty is cogently argued in Ref. 269. For more technical detail *see* Ref. 256, for a basic point about sea-level rise Ref. 258, and for more about the politics Ref. 247.

258. More precisely, sea-level rise would almost certainly be unstoppable, and would be likely to proceed at a substantially undiminished rate for a century or more — perhaps several centuries — after stabilization of the accumulated atmospheric concentrations of long lived greenhouse gases. This is what climatologists call the 'commitment' to future sea level rise. See for instance Ref. 256, p. 45, Fig. 25 (model predictions spanning 5 centuries), showing inexorable rise over the centuries after greenhouse-gas

stabilization; this feature is more significant than the precise scaling of the sea-level values marked on the vertical axis. To appreciate the very large uncertainties in the latter, *see* p. 385 of Ref. 256, and *see* also — NB — the *corrigendum* to the published versions of this Note and Note 295, reproduced below at the end of the notes and references.[400] The implication is that the uncertainties about magnitude (though not timescale) are still greater than I indicated in the published version. Barring further surprises, though — such as a Maunder-minimum-like shutdown of solar activity — it remains very likely that sea levels will rise, and still likelier that the timescale, as such, for commitment to sea level rise will be a century or more, this last still, I think, 'at least 99%' probable.

As is well known, stabilization and eventual reduction of long lived greenhouse gas concentrations in the atmosphere would require far more drastic cuts in carbon burning than yet appear remotely possible politically, though the cuts might become politically possible, boosting the energy-efficiency industry,[155,156] if, for instance, sea-level rise attributable to human activity were to become a perceived reality.

For what it is worth, current estimates spanning the 21st century put the total sea-level inflation rate at roughly twice the underlying rate and to be somewhere between — as best we can now estimate it, which is not at all well — 10 cm and 100 cm per century, in round numbers, *plus* any extra contribution from a surging or collapse of the West Antarctic ice sheet, whether natural, man-made, or man-accelerated.[296,400] 'Surging' or 'collapse' implies melting rates more drastic than currently forecast, as seems possible in view of great uncertainty about the water-lubricated dynamics of ice streams grounded below sea level. This might add perhaps an extra metre per century for several centuries.

Unstoppability has sometimes been challenged. It has been proposed from time to time that the thermal forcing by the excess greenhouse effect can itself be counteracted by some affordable technological fix, by some imagined feat of large-scale 'geo-engineering', sustained over centuries by unspecified and unprecedented social means. This seems to ignore not only experience with technological 'revenge effects'[237] but also, for instance, experience with real human societies, in particular with the threat of national and international litigation — in a free-market world at least — to say nothing of other forms of conflict amongst perceived winners and losers. For a thoughtful discussion *see* S. H. Schneider, 'Geoengineering: could — or should — we do it?' *Climatic Change*, 1996, **33**, 291–302. The threat of litigation seems to have been enough, in the early 1970s, to stop a relatively simple project, the American STORMFURY project to mitigate hurricanes by cloud seeding.

259. D. L. Reanney: 'The death of forever: a new future for human consciousness'; 1991, London, Souvenir Press, 270 pp. (ISBN 0 285 63271 X). A bit shaky on quantum mechanics, but has some important ideas on 'human becoming', on the avoidance of the spiritual abyss, of the nonsense of brutal materialism and brutal biological determinism,[129] and on acknowledging that questions about subjective experience near death are questions of personal faith and not science.

260. S. Jasanoff *et al.*: 'Conversations with the community: AAAS at the millennium', *Science*, 1997, **278**, 2066–2067. A useful summary of recent thinking by the AAAS, the American Association for the Advancement of Science, about the crisis in public understanding and the role of science in society. There is a web site for an open forum on these issues: `http://www.sciencemag.org/feature/data/aaasforum.shl/` *See also*, for instance, R. A. Pielke Jr and R. Byerly Jr: 'Beyond basic and applied', *Physics Today*, 1998, **51** (2), 42–46, giving more discussion of what is now being widely talked of as the new social contract for science,[261] which will be determined by 'political decisions with scientific input ... not scientific decisions implemented through politics'. The crisis in science *is* the crisis in public understanding — including the public understanding not only of science but also of auditing.[198,248]

261. J. Lubchenko: 'Entering the century of the environment: a new social contract for science', *Science*, 1998, **279**, 491–497. A followup to Ref. 260, written by the President of the Association, making the case for a new social contract for science — meaning mainly its financial support — in return for a commitment by scientists to something that is unprecedented, namely to recognize that 'we now live on a human-dominated planet' and that this requires something else that is unprecedented: serious attention to what is happening to our planetary life support system. At present, for instance, 'only a few of the thousands or so new chemicals released each year are monitored; the biological effects of most are unknown ...'

262. G. Easterbrook: 'Science and God: a warming trend?', *Science*, 1997, **277**, 890–893. This extended news article usefully summarizes the confusion and conflation between questions about spiritual health on the one hand, and questions about explaining natural phenomena on the other. 'In postmodern academic culture, the majority of scientists think that to be taken seriously they must scoff at faith.' If such scoffing is considered to be part of professional scientific behaviour, then we, the human species, are indeed heading for trouble. *See* also C. Raymo: 'Skeptics and true believers'; 1998, New York, Walker, 300 pp. Perhaps a 'reverence for life and profound respect for natural... processes... can inspire

some kind of morality and ritual... I disagree with Raymo at a philosophical level, but I am filled with admiration for the clarity and force of his writing, and for the many deep insights contained in this book.' — W. Mark Richardson, in *Science*, **281**, 1969–1970.

263. The optimist can point, for instance, not only (i) to the technological and economic pressures favouring supranational markets and accessible information technologies and (ii) to the known possibilities for using market forces constructively[155,156,314], but also, for instance, (iii) to the new men's movement, 'the women's movement's missing half',[273] with its powerful suggestions for new ways toward spiritual health, toward constructive rather than destructive tribalism,[172] and (iv) — perhaps this will surprise you — to the ascendant supranational power of the mass newsmedia industry. That industry has already demonstrated its ability to think on a far longer timescale than most politicians believe they can afford to;[154] and its communication professionals are anything but naive about psychological realities and human instincts. The same mass newsmedia industry must also, inevitably, be becoming more and more aware of its large stake in non-totalitarian social stability. So we have a situation almost at an opposite extreme to that exploited by the Nazis in the 1930s. Then, for economic and technological reasons that no longer apply, a small group of politicians was able to gain almost exclusive control of information and disinformation. (One may contrast this with the use of the Internet in Malaysia to frustrate the control of information and disinformation by government, much in the news around October 1998.) On other aspects of the supranationalization of power and the technological reasons for it, *see* also Ref. 154. Further signs of life can be found on `http://www.technorealism.org`; and last but not least one can mention the very remarkable, and inspiring, experiment known as the Grameen Bank of Bangladesh.[314]

264. R. L. Sime: 'Lise Meitner: a life in physics'; 1996, Los Angeles, CA, London, University of California Press, 526 pp. A historically and philosophically important book containing much information, hitherto not widely available, about the epic story of early twentieth century physics. *See* p. 174 concerning the premature announcement in 1937 of absolute certainty about the transuranic elements, subsequently shown to be wrong by more careful experiments plus the discovery by Meitner and Frisch of a new and better fitting model not previously thought of, that of nuclear fission — in Niels Bohr's words,[189] 'what idiots we all have been!'

265. S. Weinberg: 'The first elementary particle', *Nature*, 1997, **386**, 213–215. Musings by a leading physicist on the centenary of Joseph John Thomson's discovery of the electron and on which, if any, particles can be regarded as 'elementary'. Here Weinberg, with admirable caution, ends by saying 'We do not know in advance what are the right questions to ask, and we often do not find out until we are close to an answer.' *See* also the remarks by another leading theoretical physicist, Edward Witten, in *Nature*, 1996, **383**, 215–216. Witten writes (in essential agreement with, for instance, Bell,[146] Bohm, Dowker and Kent,[213,221] Goldstein,[215] Percival,[225] Penrose,[149,297] and an increasing number of other experts today) that '... we face a contradiction between quantum field theory and general relativity similar to the contradictions [in classical physics] that led to quantum mechanics', containing 'the seeds of an upheaval as profound in its own way as the discovery of quantum mechanics or relativity.'

266. S. Yearley: 'Restoring respect for science', *Science and Public Affairs* (London, Roy. Soc.), Spring 1997, 42–45. The author, a sociologist, highlights the role of 'trust and judgment' in successful and credible science and argues that their role — and, by implication, the role of the scientific ideal and ethic — needs to be made publicly clearer.

267. J. Durant: 'Beyond the scope of science', *Science and Public Affairs* (London, Roy. Soc.), Spring 1997, 56–57. Both this and the article by Fisk in the same issue[268] give sensible discussions of the usefulness and limitations of science, showing very clearly why scientists, and politicians, must resist the pressures to conflate science and politics.

268. D. Fisk: 'Sound science and the environment', *Science and Public Affairs* (London, Roy. Soc.), Spring 1997, 46–49.

269. T. N. Palmer: 'A nonlinear dynamical perspective on climate prediction', *J. Clim.*, 1998, to be published. The atmosphere–ocean–cryosphere–biosphere system is a nonlinear dynamical system. What is already known about the general behaviour of such systems[186] implies still greater uncertainty than one might gather from Ref. 257, especially about early warning signals. Palmer's paper uses simple but apt analogies to bring out these points.

270. J. Ashby: 'Mad cows, bats and baby milk', *Nature*, 1996, **382**, 109. Breaking the vicious circle (openness → sensational headlines → scientists' reaction → coverup charges) requires education 'in the scientific process and ... relative risks.' Here 'scientific process' does not mean what some sociologists mean by it.[209,232] It means, most essentially, respect for the scientific ideal. The 'mad cow' affair is a sufficient illustration. The two basic points about BSE or 'mad cow disease' must have been obvious from the outset to anyone who respected the ideal and knew the scientific background. The first was,

and still is, that grossly unnatural feeding — giving cows feed of a kind they never evolved to cope with — must exert new and unknown kinds of selective pressures on disease agents.[139] The second was, and still is, the great scientific uncertainty about the particular disease agent involved. Both basic points were missed, or ignored, by the UK government and civil service until years after the first moves in the 1980s to regulate cattle feed. This was a case of being unwise *after* the event. It took the best part of a decade to achieve official recognition of the need to avoid contamination of the food chain as a real need, implied by the large scientific uncertainty — not just a 'public relations need' as those in power perceived it. This last perception, as evidenced by the pattern of government action and inaction, by the large shortfall in compensation payments for instance, and by the making of cattle feed regulations while not enforcing them, sent a strong message that the risks and uncertainties were not taken seriously. That message must have influenced those farmers who, for instance, eschewed compensation and sold manifestly infected cattle, or fed cattle with pig or poultry feed, unregulated at the time. None of this could have happened in a society that had good lines of communication and significant respect for the scientific ideal. Notes 242, 245, and 249 comment further on the political aspects and their implications for the points I am making here. *See* also the remarks on the gambling instinct in Note 189 and in the main text. It is quite possible that those who said that Beef is Absolutely Safe, and cut costs by not enforcing such regulations as there were, knew very well that they were gambling. For a good summary and update see *Nature*, **392**, 532–533. Proceedings of the 1998–1999 government inquiry into the BSE affair are available at `http://www.bse.org.uk`.

271. N. Lebbrecht: 'When the music stops ... managers, maestros and the corporate murder of classical music'; 1996/97, London, Simon and Schuster/Pocket Books, 455 pp. Illustrates the 'winner take all' culture and the damage it does. There is a glimmering of hope at the end, from the small music festivals and recording companies that manage to escape the clutches of the strongest supranational market forces, e.g. 'Marlboro radiates a moral counter-culture', p. 411.

272. B. Levin: 'The pendulum years: Britain and the sixties'; 1977, London, Pan Books/1989, Sevenoaks, Sceptre, 447 pp. The quotation is from Chap. 4.

273. E.g. S. Biddulph: 'Manhood: an action plan for changing men's lives', 2nd edn; 1995, Sydney, Finch Publishing, 261 pp., ISBN 0 646 26144 4. The publication of this lucid and insightful book about 'the women's movement's missing half' by Steve Biddulph, an Australian family psychologist, is one among many signs of the sort of organic cultural change that is possible, and already happening. 'To get real, we have to dig down deeper.' For one thing, the tendency for industrial revolutions to separate fathers from sons has dangers that are obvious once thought of, yet only just beginning to be widely recognized.

274. J. D. Barrow: 'Theories of everything: the quest for ultimate explanation'; 1992, London: Vintage, 223 pp. First published by Oxford University Press, 1991.

275. W. Clocksin: 'Cyborg discourse', *Nature*, 1996, **381**, 34–35. 'Cyborg' means 'cybernetic organism', an intelligent system composed of people and machines, 'considered to be interchangeable' — an astonishing mistake that overestimates, by a combinatorially large factor, current levels of machine 'intelligence'.[205] It also shows profound ignorance of what a biological organism is.[205]

276. R. J. Williams and D. L. Heymann: 'Containment of antibiotic resistance', *Science*, 1998, **279**, 1153–1154. This summarizes the latest perspective from the World Health Organization. E.g. 'Twelve million antibiotic prescriptions to adults in the United States in 1992 were for upper respiratory tract infections and bronchitis, on which these drugs have little or no effect ...' Again, market forces are exacerbating what is now recognized as a serious and costly problem: 'There must be a distinction between prescribers and providers so that the prescribers (or their institutions) make no financial gain from the prescription ... at present, prescribers receive much of their continuing education from the pharmaceutical industry'.

277. Fuller notes and references are available on the Internet at the web and ftp sites `http://www.atmos-dynamics.damtp.cam.ac.uk/people/mem/` and `ftp://ftp.damtp.cam.ac.uk/pub/papers/mem/`, together with two MPEG (`.mpg`) files illustrating the 'walking lights' phenomenon (*see* Note 31 of Part I), for download in binary mode. All relevant file names begin with the eight characters `lucidity`. In addition, a 'walking lights' demonstration is now displayed automatically on my web home page, `http://www.atmos-dynamics.damtp.cam.ac.uk/people/mem/` as an animated `.gif` file viewable through most browsers.

278. R. M. Pirsig, 'Zen and the art of motorcycle maintenance'; 1974, Bodley Head, 412pp. About halfway through Chap. 26, pp. 311–312 in this original edition, there is a perceptive discussion of how to cultivate lateral thinking, or 'giving the subconscious every chance'.[279] Pirsig writes of the typical experience in which a seemingly unimportant 'little fact' becomes noticeable some time after getting stuck on a problem. It becomes noticeable, at least, if you are patient enough to give it a chance. It is 'asking in a timid, humble way if you are interested in it.' Pirsig continues, 'Be interested in it. At

first try to understand this new fact not so much in terms of your big problem as for its own sake. That problem may not be as big as you think it is. And that fact may not be as small as you think it is. It may not be the fact you want but ... often ... has friends who are right next to it and are watching to see what your response is. Among the friends may be the exact fact you are looking for.'

279. The creation of anything worth creating, in the arts and sciences equally, always seems to involve an intricate interplay between conscious and unconscious construction. This is well described on pp. 191–6 of Ref. 16 of Part I, the new (1986) edition of Littlewood's 'Miscellany': there are of course the celebrated 'eureka moments' — to quote, 'illumination, which can happen in a fraction of a second, is the emergence of the creative idea into the conscious' — but, less famously but crucially, there is the arduous preparation for such moments, impossible without 'an intense conscious curiosity about the subject ... a craving to exercise the mind on it, quite like physical hunger' lasting for many years. There is the need to find ways, different for different individuals, of 'giving the subconscious every chance'; *see* also Note 34 of Part I. There is the 'devastating experience' of losing the curiosity and the drive to undertake such arduous labour. All this should be required reading for science policymakers.

280. Chap. 11 of the book by Crick, Ref. 32 of Part I, on the visual cortex of primates, is enough to show the existence of 'hierarchies of models having different accuracies and different purposes'. What I have simplistically been calling the brain's internal model of the outside world includes, even in those parts of it most closely constrained by purely visual sensory data, what neuroscientists call different 'maps' representing different, and coarser or finer, aspects of what we see — coarse grain configuration, edges and fine detail, motion, colour, and so on.

281. Ways to limit hypercompetitive behaviour[155] are now being sought as its dangers become more and more conspicuous in a computer dependent world. One software firm, in particular, has acquired, and is said to have used, the power to decimate major competitors by hamstringing or disabling their software. It is as if one and only one car manufacturer had a set of secret weapons — whether used or not — that could make its competitors' cars slow down, or break down. There seems to be no public knowledge of whether uses of the weapons to date have been deliberate, inadvertent, or both. Such things are technically possible, for the first time in history, because of the peculiarly fragile way in which electronic computers work and because of the immense complexity of modern software. Tiny changes made in secret to proprietary operating-system and data-transfer standards can be enough to devastate a competitor's sales and multi-million dollar investment in software development. Furthermore, such a situation can only reduce software reliability — such reliability being difficult to achieve at the best of times. *See*, for instance, James Gleick's articles `http://www.around.com/microsoft.html` and `http://www.around.com/bugs.html`, and, for instance, the 'Halloween documents' in `http://www.opensource.org/halloween.html`. The Halloween documents, which became public late in 1988, are of key interest here because they have provided hard evidence, in a lengthy internal memorandum leaked from the software firm in question, confirming the existence of the secret weapons I am talking about and the intention to develop them further. The language of the internal memorandum describes the process of building such weapons as 'decommoditizing the protocols', or 'folding extended functionality into commodity protocols', or implementing 'embrace-and-extend', all of which mean the same thing: take well-tried data-transfer or other standards that work robustly and reliably, and on which everyone depends, and change them into something both more complicated and at least partly secret, and partly protected by legal intellectual property rights, thus 'raising the bar and changing the rules of the game' — with the inevitable side-effect of reducing reliability as well as putting competitors out of business. For more background, especially on ways to make software more and not less reliable, *see* Note 304*a*. Much the same issues may be expected to arise in connection with genetic engineering.

282. U. Le Guin: 'The lathe of heaven'; 1972, London, Gollancz and 1974, London, Panther/Granada, 156 pp. This wise and wonderful tale by Ursula Le Guin is more fantasy than science fiction, and so far as I remember does not even mention genetics or eugenics. But its theme has strong affinities with those of the old eugenics movement and today's dangerous fantasies about the 'reprogramming of DNA'.[130,162] A brilliant and well-meaning scientist tries to save the world through a superhuman power whose workings he does not fully understand, leading to uncontrolled carnage.

283. M. Tippett: 'Tippett on music' (ed. M. Bowen); 1995, Oxford, Oxford University Press, 318 pp. The late Michael Tippett had acutely perceptive things to say about such matters as rediscovering the sacred, in individual ways that can be authentic in our time, and about the underlying psychological realities. From Chap' 20: '... music, if it is to live, has to be searched for in those depths of the psyche where the god- and devil-images also hibernate; then how am I so sure, as I am, that I shall take no harm and the music be sane? The answers are both personal and impersonal ...' Tippett acknowledges his debts to other such seekers and explorers and their ideas, not only musicians like Beethoven but also, among many others, Carl Gustav Jung and his idea of the 'collective unconscious' — corresponding to my use

of the terms 'genetic memory' and 'Platonic', generalized to include its 'dark side' — and, before Jung, the artist–philosopher Friedrich Nietzsche. Nietzsche was keenly aware of the wonder and terror of these same depths of the psyche — including the angels, demons, and monsters to be wrestled with[166,298]; and he seems to have suffered, in Tippett's words, 'from the clear consciousness of the disintegration of our spiritual sensibility within an insatiable materialism'. Nietzsche may yet be remembered as one of the great visionaries and teachers about human nature — including some of its less congenial aspects whose existence has to be taken seriously, as I am arguing here, whether we like them or not. It seems, incidentally, that some of the more superficially belligerent ideas attributed to Nietzsche were originated not by him but by his sister Elisabeth, who survived him and became involved with the Nazi movement (e.g., recent updates in the Encyclopaedia Britannica). The book 'Der Wille zur Macht' ('The will to power'), attributed to Nietzsche, seems to have been put together entirely by Elisabeth, after his death, combining unauthorised selections from his unpublished notes with her own unacknowledged additions. I am grateful to Oliver Bühler for pointing this out.

284. Anyone wanting to simulate a bacterium on an electronic computer will need to recall that a single bacterium is a large system in comparison with a single protein molecule, with a combinatorially vast number of molecular conformations and arrangements in thermal motion on picosecond timescales. For instance the well studied bacterium *Escherichia coli* typically has length $\sim 2\mu$m and mass $\sim 10^{-15}$kg and contains an incessantly interacting and varying population of some millions of protein, nucleic acid, and other large molecules of thousands of different kinds.[299] The complete DNA sequence is now known for the K-12 strain of *E. coli* (F. R. Blattner *et al.*, *Science*, 1997, **277**, 1453–1474), and appears to imply that the bacterium is potentially able to manufacture up to 4288 different kinds of protein. The conformations or ways of folding, hence detailed functioning, of many of these protein molecules are unknown, not have we yet the means to predict them reliably. Note also that the *E. coli* bacterium has less than a thousandth of the volume of a single human neuron (Ref. 32 of Part I), a far more complicated (eukaryotic) type of cell.

285. J. Keegan: 'War and Our World'; 1998, London, British Broadcasting Corporation (ISBN 0 09 177794 1). The 1998 BBC Reith Lectures by the distinguished military historian John Keegan, who 'traced the profound impact that war has had on shaping civilization in the 20th century, explored its origins, examined the changing roles of nation states and individuals in the prosecution of war, and finally considered whether there will ever again be global conflict.' A model of lucidity that should be read alongside Ref. 166. *See* also R. A. Hinde: 'War: some psychological causes and consequences', *Interdisc. Sci. Rev.*, 1997, **22**(3), 229–245. An eminent animal and human behaviourist analyses the nature and cost of modern warfare, and the cultural and institutional aspects of its perpetuation. Complements Ref. 166's insight into the 'predisposing factors' and 'eliciting factors'.

286. Even if some maverick had begun to invent art objects before 60 000 BC,[183] it might well have seen as frivolous — as an unaffordable luxury, quite obviously an impediment to migration — and probably sacrilegious as well. As a tribal elder might have said, suitably translated: 'If God had meant us to fool with beads and bracelets, he wouldn't have given us music, poetry and dance.' Or, more likely perhaps, 'Violate not the sacred shapes of our ancestral tools, lest their magic be dissipated and we be doomed.'

287. H. Bondi: 'Assumption and myth in physical theory' (The 1965 Tarner Lectures); 1967, Cambridge, Cambridge University Press, 88 pp. Though now out of date in some details (including, incidentally, tidal dissipation[295,300]), it contains a wise, lucid, and cogent warning about the limitations of science. On Final Theories, *see* also, for instance, my discussion in Part II and discussions in Ref. 171, pp. 363–365, and in Feynman, R. P., Leighton, R. B., Sands, M., 1964: The Feynman Lectures on Physics, Vol. II, Mainly Electromagnetism and Matter. New York, Addison-Wesley, p. 25-10.

288. There can be no doubt but that unregulated market forces have exacerbated the situation with human diseases, by driving not only the profligate use of antibiotics but also, for instance, the growth of prostitution in Russian cities and elsewhere. Such a situation, made still worse by the unregulated use of substandard, including black market, antibiotics (tending, as it were, to vaccinate bacteria against humans),[276] provides fertile ground for the ever faster evolution of today's and tomorrow's dangerous viruses and bacteria. For instance medical professionals have already noticed a resurgence of syphilis in the West, emanating from Eastern European sources, and expect the usual consequence of increased HIV infection thence AIDS to follow (BBC news item of 4 April 1997; updates should be available on the World Health Organization's web pages, `http://www.who.ch/`).

289. E.g. T. Behan: 'The Camorra'; 1996, London and New York, Routledge, 225 pp. A historical study of the development over nearly two centuries of a powerful and politically sophisticated crime organization, whose first opportunity to establish itself came from the high unemployment in the slums of Naples in the early nineteenth century. This is one of the unintended effects of unregulated market forces in action, in a manner whose history appears to be repeating itself in Russia and Eastern Europe.

290. A brilliant and famous scientist, in 1997, said on the record that 'I don't think there's any doubt that one can simulate an earthworm's brain on a computer'. What was meant was, presumably, not a real earthworm's brain but a model brain made of textbook neurons and synapses — quite a different thing, as Notes 205 and 284 remind us.

291. Q. Ouyang, P. D. Kaplan, S. Liu, and A. Libchaber: 'DNA solution of the maximal clique problem', *Science*, 1997, **278**, 446–449.

292. D. Bouwmeester, J.-W. Pan, K. Mattle, M. Eibl, H. Weinfurter, and A. Zeilinger: 'Experimental quantum teleportation', *Nature*, 1997, **390**, 575–579. *See* also Refs. 293:

293. D. Boschi, S. Branca, F. De Martini, L. Hardy, and S. Popescu: 'Experimental realization of teleporting an unknown pure quantum state via dual classical and Einstein–Podolsky–Rosen channels', *Phys. Rev. Lett.*, 1998, **80**, 1121–1125. *See* also the news item in *Nature*, 11 Dec. 1997, **390**, 551–552 and in *Physics Today*, **51**(2), 18–21.

294. A. Bloom: 'The closing of the American mind: how higher education has failed democracy and impoverished the souls of today's students'; 1987, London, Penguin, 392 pp. A substantial and erudite discussion of the significance and history of various kinds of cultural relativism, seen from the humanities' side.

295. NB: The following is more or less the same as the published version of this note; see the *Corrigendum* in Note 400 below. It is to be published in the December issue of Interdisc. Sci. Revs.

Here is the published version, which I now realize was embarrassingly simplistic, though still part of the story: The multi-century timescale of the underlying sea level inflation rate is robust in the sense that drastically changing it would require one or both of the following two changes, the first of which is unlikely in even the most extreme — the most anti-conservative — of future global-change scenarios,[256] and the second too remote to consider seriously, about as probable as things falling upward. The first is for the roaring forties and fifties to cease roaring, in the sense that the wind stress on the Southern Ocean is drastically reduced in middle to high southern latitudes, such as the latitude of Cape Horn. The second is for the Moon to go away. The point is that surface temperature changes penetrate into the ocean at a rate governed mainly by the rate of what oceanographers call diapycnal mixing, or mixing across the ocean's stable density stratification, a process that requires mechanical stirring a portion of which does work against gravity. The total mechanical rate of working required to support such stirring, sufficient to maintain the observed stratification, is of the order of 2 TW (2×10^{12} watt)[300] and is available only from tides (whose total rate of working is well known to be 3.7 TW of which 3.2 is lunar and 0.5 solar) and from surface winds, whose total rate of working is less well known but appears to be of the same order of magnitude as the tidal rate and to be dominated by winds over the Southern Ocean (C. Wunsch: personal communication). A careful, up to date discussion is given in Ref. 300. We have little detailed understanding of how, when, and where in the ocean all the diapycnal mixing takes place, and of why it should be taking about 2 TW out of the total of, say, 6 to 8 TW available (competing with other energy sinks such as turbulence in shallow marginal seas). What evidence there is says that the diapycnal mixing is extremely intermittent in spacetime, making it almost impossible to locate and observe. But we do know with high confidence that without the mechanical stirring — and this prediction is robust — the ocean apart from a warm layer near its surface would be unstratified, and at temperatures close to freezing. This is a thermal structure grossly different from the stratification actually observed.[300,301] We therefore know from the observed structure that the mechanical stirring and consequent diapycnal mixing must be taking place somewhere, and furthermore we know its globally averaged order of magnitude.[300] This works out to be equivalent to a globally averaged vertical diffusivity $\sim 10^{-4}\mathrm{m}^2\mathrm{s}^{-1}$. The associated diffusion timescales for downward heat penetration range from 3 to 30 centuries, in rough order of magnitude, when depth scales are taken in the range 1 to 3 km. Such timescales furthermore are indifferent, in their rough order of magnitude, to whether or not the so called thermohaline circulation is weakened or shut off, a feature of some global-change scenarios that is crucially significant for regional climate but not, for the reasons just given, so crucially significant for the underlying sea level inflation rate.

296. R. A. Warrick, C. Le Provost, M. F. Meier, J. Oerlemans, and P. L. Woodworth, P. L., 1996: 'Changes in sea level', in Ref. 256, Chap. 7, 361–405. *See* Fig. 1.9, p. 385.

297. S. W. Hawking and R. Penrose: 'The nature of space and time'; 1996, Princeton, NJ, Princeton University Press, 41 pp.

298. 'Wer mit Ungeheuern kämpft, mag zusehn, daß er nicht dabei zum Ungeheuer wird. Und wenn du lange in einen Abgrund blickst, blickt der Abgrund auch in dich hinein.' Roughly translated, this reads 'He who fights with monsters might take care lest he thereby become a monster. And if you gaze for long into an abyss, the abyss gazes also into you'. Oliver Bühler has told me that the word 'monster'

only partly captures the meaning of 'Ungeheuer', which along with 'Abgrund' evokes feelings of deeper mysteries. The quote is from Nietzsche's 'Jenseits von Gut und Böse'; 1886, Chap. 4, §146.

299. F. C. Neidhardt and H. E. Umbarger: 'Chemical composition of *Escherichia coli*', in *Escherichia Coli* and *Salmonella*: Cellular and Molecular Biology, 2nd edn, (ed. F. C. Neidhardt *et al.*), 13–16; 1996, Washington, DC, ASM Press, 2822 pp. *See* also Note 205. For variations during the life cycle, *see* H. Bremer and P. P. Dennis: pp. 1553–1569 of same publication. I am grateful to Dr Vassilis Koronakis for his advice and for drawing my attention to these references.

300. W. Munk and C. Wunsch: 'Abyssal recipes II: energetics of tidal and wind mixing', *Deep Sea Res.*, 1998, **45**, 1976–2009.

301. R. M. Samelson and G. K. Vallis: 'Large-cale circulation with small diapycnal diffusion: the two-thermocline limit', *J. Marine Res.*, 1997, **55**, 223–275.

(The following references were added after ISR publication:)

302. P. A. David: 'From market magic to calypso science policy: A review of Terence Kealey's *The Economic Laws of Scientific Research*', *Research Policy*, 1997, **26**, 229–255. A meticulous and thorough exposure of the many factual errors and the 'flawed economic logic' in Kealey's book,[245] 'the telling of stories that blatantly disregard the evidence'. The reviewer, Paul A. David, is a respected economist and economic historian and a Fellow of the British Academy. David also reminds us how much is at stake. 'It is entirely conceivable that... [the science policy reassessments now being urged] will amount to more than merely another fraught, but transient episode in the lives of modern government bureaucracies... From that refreshed policy watershed would flow a stream of governmental and industrial decisions affecting the course of scientific and technological developments well into the twenty-first century — for better or for worse.'

303. R. Galvin: 'Science Roadmaps' (editorial), *Science*, 1998, **280**, 803, 8 May 1998. A 'roadmap' in this sense is a major, book-size, multi-author 'assessment document' (such as Ref. 256 above) that tries to provide 'an extended look at the future of a chosen field of inquiry... from the collective knowledge and imagination of the brightest drivers of change in that field'. Such roadmaps can consist of 'statements of theories and trends, the formulation of models, identification of linkages among and within sciences, identification of discontinuities and knowledge voids,... the identification of instruments needed to solve problems...', etc. The author, Robert Galvin, an industry leader, goes on to give specific illustrations, e.g., 'The Santa Fe Institute has given its unqualified support to science roadmapping and is preparing a Novel Computational Roadmap' on the basic research 'needed now to create computing technologies... 15 years hence'.

304. In Stephen Hawking's words: 'Some people never admit that they are wrong and continue to find new, and often mutually inconsistent, arguments to support their case... It seems to me much better and less confusing if you admit in print that you were wrong.' On p. 151 of S. W. Hawking: 'A brief history of time'; 1988, London, Bantam Press, 198 pp. *See* also, e.g., D. F. Gray: 'A planetary companion for 51 Pegasi implied by absence of pulsations in the stellar spectra', *Nature*, 1997, **391**, 153–154. *See* also the accompanying News and Views item by Geoffrey Marcy on p. 127 of the same issue of *Nature*, summarizing the recent resolution of controversies about planets around Sun-like stars and well illustrating the important role of honest retractions, like this one by David Gray: in Marcy's words, 'science at its healthiest'. For insight into how, historically speaking, respect for the scientific ideal and ethic got a foothold in human society — against the odds — and why it did so in renaissance Europe and not, for instance, in Imperial China, see P. A. David, 'Common agency contracting and the emergence of "open science" institutions,' *Amer. Econ. Rev.*, 1998, **88**, 15–21. Again the point is that the usual 'imperative of secrecy' was overcome, with 'utter improbability', by the accidental discovery that openness and peer review led to spectacular progress in scientific and mathematical understanding. The same thing has been demonstrated afresh by today's free software (open-source software) community:

304*a*. The ideal and ethic of the *open-source software community*, alias *free software community*, which created the Internet as well as the remarkable GNU software tools, are cogent and very practical examples of what I mean by the scientific ideal and ethic and their power to generate reliable knowledge — as manifested, in this instance, by a very remarkable phenonenon: complex computer software systems that work reliably. Among many specific examples, perhaps the most spectacular has been the recent development of the operating-system kernel called Linux for personal computers and networks, now beginning to be used commercially. The complete GNU/Linux system, despite its great complexity, is now widely regarded as the most reliable of today's general-purpose software systems. This is admitted even by the developers of the rival closed-source commercial systems, important parts of which are being marketed hypercompetitively[155,281] and whose ever-changing standards and protocols are not fully

open, so that secret changes can be used to maintain market dominance. In the words of the first Halloween document,[281] Linux and other open-source software projects have harnessed a large 'collective IQ' in a manner that is 'simply amazing', giving computer systems a 'robustness... at every level' that is 'great... for overall stability'. Stability means, of course, resistance to crashes of the computer system or network hence draining of human resources. The first Halloween document states that GNU/Linux has already been deployed in 'mission critical, commercial environments' that have already generated 'an excellent pool of public testimonials'. Crucial to this success has been the continuing 'reality check' of openness to unfettered scrutiny and experimentation by anyone interested, and the freedom of anyone interested to think about the myriads of unforeseeable problems and to contribute improvements — the same 'parallelization' of problem-solving that has produced reliable scientific knowledge in general. *See* for instance Eric S. Raymond's articles `http://www.tuxedo.org/~esr/writings/cathedral-bazaar/` and `http://www.tuxedo.org/~esr/writings/homesteading/`, and associated links. *See* also, for instance, James Gleick's article in `http://www.around.com/bugs.html`, and an interview with one of the idealists and founding fathers of the open community that made these developments possible, Richard Stallman of MIT, in `http://www.kde.org/food/rms.html`. The *legal framework* that made them possible is described in `http://www.gnu.ai.mit.edu/copyleft/copyleft.html`.

305. T. Curtin: 'Being rational about the irrational', *Science and Public Affairs* (London, Roy. Soc.), Summer 1998, 12–14. 'The problem is that science is slow to find friends, to forge strategic alliances, to be flexible in its political thinking... quick to tag people as either friends or enemies.' Recommends the book by O. d'Herbemont and B. Cesar: 'Managing sensitive projects: a lateral approach'; 1998, London, Macmillan.

306. B. L. Silver: 'The ascent of science'; 1998, Oxford, University Press, 534 pp. A working scientist's 'hitchhiker's guide to science' for intelligent lay people, especially concerned citizens of democracies. It gives a well informed, down-to-earth survey of science, anti-science, and their intertwined histories over the past few centuries, all the way through to the professional writers in today's business of 'science trashing'. Very clear on the fundamental nature of science, emphasizing its imperfections, uncertainties, and open-endedness, as well as its self-correcting ability and consequent successes. Starts well with a chapter headed 'In which, among other things, we will look at the fallibility of science and of scientists, and ask if anyone can be trusted.'

307. G. Delacôte: 'Putting science in the hands of the public'. *Science*, 1998, **280**, 2054–2055. A passionate advocacy of the 'informal science education movement', with emphasis on the 'learner-centric approach' with hands-on exhibits, as in the 'science centers of which there are over 300 in the United States alone'. Goéry Delacôte is professor of physics at the University of Paris and executive director of the San Francisco Exploratorium. His recent book 'Savoir Apprendre les nouvelles methodes' (Paris, Odile Jacob, 1996, 277 pp.) argues for educational reform.

308. P. Cammack, 'Globalization and the death of liberal democracy.' *Europ. Rev.*, 1998, **6**, 249–263. Cogently discusses some likely directions of political and cultural change in the near future, with considerable optimism that these changes will be more organic than catastrophic. Argues, however, that the dominant form of nation-state will soon be, or perhaps already is, what political scientists call 'elective democracy', responsive primarily to global-scale market forces. This could be successful in preventing the reversion to repressive, warmaking totalitarianism[263] but, equally, might not come very close to the ideals and absolutes of liberal democracy. There is still room for an optimist to argue that market forces and the costs of conflict and spiritual malaise could, however, in the long run, help toward something like a humane balance of rights and duties.

309. G. J. Vermeij, 'Fossils and the social future of science', *Science*, 1998, **281**, 1444–1445. Along with others, e.g. Stuart Kauffman,[204] the paleobiologist Geerat Vermeij argues that recent human economic and social evolution has strong analogies with — is, in a sense, a case of — the kind of 'evolutionary ferment' that characterized the great radiations or adaptations that followed past environmental and other upheavals in the 'fitness landscape'. Economic and social evolution, and cultural evolution in general, resemble genetic evolution after allowing for the shorter timescale (of cultural evolution exploiting pre-existing genetic diversity), not least because economic costs and benefits have their biological counterparts, beginning with food supply. So the geneticist Theodosius Dobzhansky's remark that 'Nothing in biology makes sense except in the light of evolution' could be replaced, Vermeij argues, by 'Everything in evolution makes sense in the light of economics', or equally, and conversely, 'Nothing in economics makes sense except in the light of evolution.' This seems to offer valuable insights into the nature of the transition or transitions we are now undergoing. Exactly as in analogous episodes of genetic evolutionary ferment, the present cultural-evolutionary ferment will replace the present kind of growth-dependent, chaotic or dynamically unstable economy by something more stable, which grows much less rapidly if at all. Whether that will be describable as a civilization is of course a separate question. Fundamentally

similar transitions from explosive growth and diversification to relative stability can be observed, in miniature, in populations of bacteria whose environment is manipulated in the laboratory.[309])

309. V. Morrell, 'Biodiversity in a vial of sugar water', *Science*, 1997, **278**, 390. Making use of pre-existing genetic diversity, a homogeneous-looking population of bacteria diversifies to fill the available environmental niches supplied by the experimenter; the experiment is robustly repeatable.

310. S. Dürr, T. Nonn, and G. Rempe, 'Origin of quantum-mechanical complementarity probed by a "which-way" experiment in an atom interferometer', *Nature*, 1998, **395**, 33–37. This is a beautiful clear experimental refutation of the oversimplified, textbook view that it is always energy–momentum kicks from probe particles that make particle paths uncertain. There are more subtle ways, involving quantum entanglement. The experimental idea is to use atoms as particles, and to use their internal states as distinguishing labels that leave the momentum of each atom undisturbed. *See* also the News and Views item on p. 12, and Penrose[149] on the related topic of 'null measurements' that do not disturb the measured system. See *also* the cautionary remarks about the word 'measurement' in Ref. 146.

    Yet further remarkable quantum entanglement/teleportation experiments has been reported by A. Furusawa *et al.*, 'Unconditional quantum teleportation', *Science*, **282**, 706–709, and M. A. Nielsen *et al.*, 'Complete quantum teleportation using nuclear magnetic resonance', *Nature*, **396**, 52–55, clearly the beginnings of a flood of papers.

311. J. Gleick: 'Genius: Richard Feynman and Modern Physics'; 1992, New York, Random House; London, Little Brown, 531 pp. This wonderful book catches Feynman's spirit: the combination of honesty, self-reliance, disrespect for tribal shibboleths, and respect — nay, passion — for the scientific ideal, including the need to speak out against the myths of absolute knowledge and absolute certainty and to expose their absurdity. Gleick also gives, at the start (p. 19), one of the best thumbnail sketches of what science is about, what I called driving in the fog: *It had already occurred to psychologists that children are innate scientists, probing, puttering, experimenting with the possible and impossible in a confused local universe... "If I do this, what will happen?" ... Every child is observer, analyst, and taxonomist, building a mental life through a sequence of intellectual revolutions, constructing theories and promptly shedding them when they no longer fit. The unfamiliar and the strange — these are the domain of... children and scientists.*

312. This threat to the integrity, independence, and credibility of science — the threat from what I am calling market-force hypercredulity — has been thoughtfully discussed by John M. Ziman, a respected physicist and science policy veteran, in his Medawar Lecture to the Royal Society of London and in a version of it published as an unusually long *Nature* Commentary: J. Ziman: Is science losing its objectivity? *Nature*, 1996, **382**, 751–754. Ziman rather pessimistically quotes a science policy report suggesting an unstoppable slide toward what amounts to tobacco company science, called the 'transition from mode 1 to mode 2' and constituting a 'serious threat' — and Ziman is a very moderate and cautious writer — a 'serious threat' to the objectivity that '... makes science so valuable in society' because of its 'well-deserved reputation for impartiality on material issues'. The threat is indeed serious, but an optimist can reply that some societies might, conceivably, wake up and decide to stand up to that threat.[263] Indeed there are already (in 1998) signs of such an awakening, at least in the United States and Western Europe, including the UK.

313. Bill Watterson has put on record, in a Calvin and Hobbes cartoon, his view of the 'wilful and determined ignorance'[247] which the conviction politics of the 1990s has illustrated all too well, especially in the USA. Calvin and Hobbes are riding along in their red wagon, careening through the woods:

    Calvin: 'It's true, Hobbes, ignorance is bliss!' Once you know things, you start seeing problems everywhere... and once you see problems, you feel like you ought to try to fix them... and fixing problems always seems to require personal change... and change means doing things that aren't fun! I say phooey to that!'

    Moving downhill, they begin to pick up speed.

    Calvin (looking back at Hobbes): 'But if you're wilfully stupid, you don't know any better, so you can keep doing whatever you like! The secret to happiness is short-term, stupid self-interest!'

    Hobbes (looking concerned): 'We're heading for that cliff!'

    Calvin (hands over his eyes): 'I don't want to know about it.'

    They fly off the cliff:

    'Waaaugghhh!'

    After crash landing,

    Hobbes: 'I'm not sure I can stand so much bliss.' *Calvin*: 'Careful! We don't want to learn anything from this.'

(Cartoon by Bill Watterson, copyright © Universal Press Syndicate, 17 May 1992)

314. M. Yunus: 'Alleviating poverty through technology.' *Science*, 1998, **282**, 409–410. Also, e.g., `http://results.action.org/summaryp.html`. Professor Muhammad Yunus is the founder of the Grameen Bank, which I mention under the heading 'An optimist's millennium'. Yunus tells of a personal odyssey, starting in his home country, Bangladesh, that led to the establishment of the Grameen Bank and of similar organizations in, so far, 58 other countries including now the USA. It started when, as a young academic, he noticed the kind of thing that the audit culture does not notice — and something too simple for most of us to grasp — that by lending a few dollars to a highly skilled craftswoman he could free her from a form of slavery, in which she and her family received near-zero reward for seven days a week of hard, highly skilled work. That slavery depended quite simply on what you and I, dear reader, might well call an information blackout: the tight control of information, as well as of the money supply, by local moneylenders in isolated rural areas. The word 'Grameen' means 'village', or 'of the village'.

Since that first loan, the bank has lent a total of about $2 billion, at the time of writing (1998). It is a financially sustainable venture that receives no subsidy, and is based on six principles: (1) that it lends only to the poorest of the poor among the rural landless, (2) that it remains women-focused (94% of its customers are women, promoting stability and long-term thinking), (3) that the loans are made without collateral or security, (4) that the borrower, not the bank, decides the business activity for which the loan will be utilised, (5), that the bank helps and supports the borrower, and (6) that interest charges will be no more and no less than needed to maintain the bank's financial sustainability, i.e. its independence from grants and donations, to say nothing of political favours, etc.

315. O. Morton, 'Between opinion and fact', *Newsweek*, 8 December 1997, p. 19. This wise piece of scientific journalism by Oliver Morton talks sense about how to handle climate-change uncertainties. It also describes one of the scientist's working distinctions very well: "There's a good rule of thumb for telling a consensus from a fact. If you flatly refuse to deal with a fact, then you rule yourself out of the game; if you don't go along with a consensus, you can still be a reasonably respected scientific player."

317. D. D. Hoffman: 'Visual intelligence: how we create what we see'; 1998, New York, London, Norton, 294 pp. An important sequel to Richard Gregory's classic 'The intelligent eye'[24] and David Marr's 'Vision',[5] with a wealth of beautiful illustrations showing in many ways how perception works by model-fitting, or 'active construction' as Hoffman aptly calls it. With great cogency and lucidity, and in considerable detail, the book explains how far experimental psychologists have progressed with inferring the brain's simplest, most deeply embedded, and most culture-independent sets of (Bayesian) prior probabilities, called innate 'rules' after Chomsky. They include the piecewise-rigid assumption underlying the 'walking lights' demonstration, and many others. (For instance, the drawings on p. 97 illustrate evidence for the prior probabilities relevant to the Matisse sketch shown in Part I.) It is interesting that, even in a book published as the 'virtual reality' industry begins to take off, in the year 1998, Hoffman feels the need to argue, again and again, against what I referred to in Part II as the 'veridical perception fallacy'.

318. I. Berlin: 'The proper study of mankind', ed. H. Hardy and R. Hausheer; 1997, London, Chatto and Windus; 1998, Pimlico/Random House, 667 pp. An anthology of essays by the late Isaiah Berlin, one of the wisest thinkers and scholars in what is called the history of ideas — more precisely, the history of those ideas that have been influential in Western human societies and political movements. A recurrent theme in Berlin's writings has been the role of hypercredulous belief and its destructive as well as its evolutionary power, magnified in recent centuries by the printing press and other communication media — how ideas, methods, and models that succeed in one area, such as Newtonian physics, have been seized upon as Answers to Everything and misapplied to vastly different areas, such as human affairs, often provoking backlash and wreaking havoc. Following Alexander Herzen, Berlin reminds us how this havoc has included, on a gigantic scale, human sacrifice[166] 'on the altars of abstractions — nations, Church, party, class, progress,...'. But despite all this, Berlin in a wonderfully optimistic way helps to show how we may yet learn to use our power of rationality more wisely, judiciously, and aptly than in the past. For instance, high-quality historical research may perfectly well be 'scientific' in the sense of recognizing that model-fitting is involved, and of respecting evidence and goodness of fit, while recognizing also that the models are bound to be complicated — enormously more so than, say, Newton's laws — and moreover that to be useful those models must have a large unconscious component drawn from the repertoire of our unconscious mental models of human nature and human propensities, constituting our own highly evolved social intelligence.

319. I note that exactly this point is made — that unregulated market forces are more like a chaotically-dynamic wrecking ball than a well behaved simple pendulum — in a recent book by one of the acknowledged international experts on market forces: Soros, George: 'The crisis of global capitalism'; 1997, Little Brown,

400. *Corrigendum* (which appeared, missing some proof corrections, in the December 1998 issue of *Interdisc. Sci. Revs.*): I must retract certain statements near the beginning and end of Note 295 on sea level rise, particularly (a) the statement 'that surface temperature changes penetrate into the ocean at a rate governed mainly by the rate of... diapycnal mixing, or mixing across the ocean's stable density stratification', and (b) the suggestion that the timescales are 'indifferent' to circulation patterns. I must also retract the statements in Note 258, that, if greenhouse forcing were constant, sea levels would rise 'at fairly near a constant rate' (line 2) or at a rate 'constant, to a first approximation' (line 16), for a century or more. All these statements pretend to a more precise knowledge than is available today. In particular, the diapycnal mixing discussed in Note 295, while part of the story, might not dominate, especially in the first century of sea level change. It might even be relatively unimportant — especially in the first century — if the geographical patterns of surface warming and upper ocean circulation were to develop in certain ways, so as to favour the transport of heat anomalies along, rather than across, the sloping stratification surfaces. In today's oceans, water can reach depths of order 1 km or more by moving sufficiently far along such surfaces, starting near the top of the ocean at certain high latitude locations; and this has timescales up to a century or more, a point that to my great embarrassment I overlooked. *See*, e.g., J. A. Church et al., 'A model of sea level rise caused by ocean thermal expansion', *J. Clim.*, 1991, **4**, 438–456. The upshot is that my main point about sea level rise and its timescale, as made on page 47a of the published version and in Note 258, is almost certainly correct for practical purposes *except* that the precise rate of sea level rise will depend not only on the level of greenhouse forcing but also on hard-to-predict changes in surface temperature patterns and upper-ocean circulation patterns, adding yet more to the uncertainties. On top of all this, some researchers consider that the West Antarctic Ice Sheet, much of which is grounded below sea level, might melt faster than predicted by current models of ice flow dynamics, possibly adding something like an extra metre per century to the total rate of sea level rise. West Antarctic ice volume above sea level corresponds to about 5 metres of sea level rise. The fog we are driving in is still denser than I thought. I am grateful to Trevor McDougall, Sarah Raper, and Stephen Schneider for making me aware of the mistakes in my reasoning. (Thus I have inadvertently illustrated my own point, made in Part I, p. 201, about how, by the omission of 'trivialities', one can 'fail to detect actual mistakes in one's own thinking'.)

I take the opportunity to call attention to Notes 132 and 177 of Part III, which correct slips in Parts I and II. At the end of Note 132, 'bacterial populations' should of course read 'bacterial and viral populations'. At the end of Note 142, 'a year or so' should read 'some months'. Further to Note 245, *see* the detailed analysis by a respected economist and economic historian, P. A. David: 'From market magic to calypso science policy: A review of Terence Kealey's *The Economic Laws of Scientific Research*', published in *Research Policy*, 1997, **26**, 229–255. I thank John Ziman for pointing out this reference, which politely, firmly, and meticulously exposes the 'flawed economic logic' in Kealey's book, 'the telling of stories that blatantly disregard the evidence'.

FIGURE CAPTIONS

Note: these figures are downloadable from the same ftp site ftp://ftp.damtp.cam.ac.uk/pub/papers/mem/ (filenames lucidity-figP1.gif, lucidity-figP2.gif, lucidity-figP3.gif)

1 Skull capacities of some of our ancestors and their close relatives, from the fossil record (pluses: australopithecines; asterisks: early *Homo (H. habilis, H. rudolfensis)*; filled squares: *Homo erectus*, including *Homo ergaster*; open squares: archaic and modern *Homo*). Ref. 173, from which the figure is taken with kind permission, reviews this and several other lines of palaeoanatomical evidence that are consistent with an evolutionary preconditioning for language, intensifying roughly 2000 millennia ago (*see* text), followed by the rapid co-evolution of brain and language over the past few hundred millennia in a genetic–memetic 'evolutionary arms race'.[174,161] (The data shown in the picture will probably need some revision as improved methods of measuring cranial capacity come into use; see *Science*, 1998, **280**, 1714 and 1730–1731. Such revisions, and data from further samples as they are discovered, seem more likely to affect detailed timings rather than the overall trend.)

2 Side view of, and cut through, the brain of a right-handed modern human, after Ref. 175. The cut, more precisely a view from above of the part of the brain below the cut, shows some of the left–right asymmetry including the large Wernicke's area (shading at left), essential to understanding language. The patterns of folds or sulci and their evolution over the timespan of Fig. 1 can be traced in fossil skulls.[161,173] The Sylvian sulci, the large folds along which the front part of the cut is made, also show left–right asymmetry: the Sylvian sulcus is lower, and the Broca's and adjacent areas larger, on the left than the corresponding features on the right. Broca's and adjacent areas are associated with the fine control of speech vocalization.

3 The astonishingly close fit between the radiation law or Planck function for black-body radiation at temperature 2.728 ± 0.004 K (thin curve) and recent measurements of the mean cosmic background microwave radiation. The measured points and their statistical error bars are invisible. They are smaller than the thickness of the plotted curve. From Ref. 223; q.v. for full technical detail. To convert the values at left from megajansky per steradian to SI units, W $m^{-2}(m^{-1})^{-1}sr^{-1}$, multiply the values by $2.99792458 \times 10^{-12}$. The possibility, and significance, of such goodness of fit is ignored or discounted in today's 'cultural relativist' and 'social constructivist' philosophies of science.