'Grayling brings satisfying order to daunting subjects' Steven Pinker

THE FRONTIERS OF KNOWLEDGE

What We Now Know about Science, History and the Mind

A. C. GRAYLING

'If there is any such person in Britain as The Thinking Man, it is A. C. Grayling' *The Times*

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To the founding students, faculty and staff of NCH and to
all who carry its legacy forward:
Animi Cultura Gaudere

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Preface

In very recent times humanity has learned a vast amount about the universe, the past, and itself. Since the nineteenth century it has unearthed thousands of years of history forgotten or wholly unknown beforehand: the history of the great pre-classical civilizations, and before that the story of human evolution. Since the beginning of the twentieth century it has made hitherto inconceivable discoveries about the physical universe at the smallest and largest scales we can so far reach, from quantum theory to cosmology and the origins of space and time. And in just the past few decades it has been able to look inside the brain to begin finer-grained mapping of its structures and to observe them actually at work.

These advances have been enormous, exhilarating, and consequential. We occupy a different and much richer universe than our forebears living as recently as the nineteenth century. Yet a remarkable fact attends these developments: whereas it was once believed that every advance in knowledge diminishes our ignorance, these recent giant strides have shown us just how little we know. Enquiry thus generates a paradox: increasing knowledge increases our ignorance. So – what do we know? And what do we now know that we do not know? And what have we learned about the nature of enquiry itself – the barriers and difficulties that have to be overcome or taken into account as our increasing knowledge increases our ignorance?

This book seeks to answer these questions in three crucial areas at the frontiers of knowledge, these being science, history, and psychology – more particularly: fundamental physics and cosmology, the discovery of the pre-classical past and human evolution, and the new neurosciences of brain and mind.

In writing often and variously about the growth of ideas and the history of philosophy, I have been deeply intrigued by questions about humanity's labours on the frontiers of knowledge, and about the nature, methods and problems of enquiry. These are questions that lie at the heart of philosophy – understood in its broadest sense as reflection on what we know, how we know it, and why it matters – because they lie at the heart of human endeavour itself. My aim in these pages is to illustrate and explore three of the most important frontiers of this endeavour, to describe where they lay and how they were advanced to where they lie now; and to discuss what their current position teaches us about what we have yet to learn.

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Introduction

What do we know about the world, the past, and ourselves? Very recently, just in the course of the last century and a half, there have been spectacular advances in our enquiries into these topics. Using the most general labels for them, we call them *science*, *history*, and *psychology* respectively, but the labels do little justice to what has been achieved in them, nor what the achievements mean, nor where they are or might be leading us. They are the result of rapidly evolving technologies of enquiry that have vastly extended humanity's observational reach, both backwards in time and across previously inaccessible scales of distance from the remotest galaxies to the intricacies of the human brain, and yet further down to the inner architecture of the atom. Each step in these advances has in its turn raised new questions, questions that beforehand were not possible to ask; and one of the chief results has been to expose a paradox: the *paradox of knowledge*, which is that *the more we know, the more we realize the extent of our ignorance*, not least in these three crucial areas of enquiry about the world, the past and the mind.

The paradox of knowledge has been made familiar by these recent advances of knowledge, but until they became so rapid and far-reaching the belief was that knowledge was *reducing* the domain of ignorance. Humankind believed that knowledge was accumulating in such a way that the prospect of reaching the frontier of knowledge itself, enabling humankind to know everything there is to know, seemed to be implicit in the unfolding success of enquiry. The dramatic reversal in this perspective is no longer a surprise, but the implications of this fact, including those that raise questions about the nature of enquiry itself, have yet to be fully grasped.

Every stage in the growth of knowledge over the course of human history has had its frontiers, and for the pioneers venturing across them the frontiers defined the *terra incognita* that lay on their other side. Quite often the direction of travel they seemed to indicate turned out to be wrong. One of the greatest questions therefore about today's frontiers is whether the directions of travel they indicate are the right ones. Of course the proper response is: who can say until you try? But it might be that there are some clues both in the history of past frontiers and in the approach to present frontiers that could help.

As it happens, in an importantly different sense of the word 'knowledge', our ancestors have known a great deal not just for thousands but for millions of years. It appears that the earliest stone tools date to 3.3 million years ago, halfway back to the point in evolutionary history when the ancestral trees of chimpanzee and human forebears diverge. The knowledge they had is *knowledge how* – that is, practical knowledge, from making tools to building shelters, mastering fire, creating cave art, domesticating animals and plants, shaping and moving huge stones, digging irrigation canals, fashioning textiles and pottery, casting bronze from copper and tin, smelting iron, and so onwards to the advanced technologies of today.

'Knowledge how' almost certainly came to be accompanied, at some perhaps quite early point, by efforts to achieve *knowledge what* – that is, theoretical knowledge, *explanations* of *why* the *how* works. The frameworks of explanation devised by our ancestors almost certainly involved imputing agency to natural forces. To explain thunder, wind, rain, and the movements of the heavenly bodies, our ancestors are likely to have inferred from their own powers of agency – the feeling of 'I caused that', as when one throws a stone into water and makes a splash – that anything that moves, emits noise, changes in any way, must have an agent, a mover, behind or within it. Moreover, the appearance of intentional behaviour in animals also doubtlessly made our ancestors think that animals have mental lives similar to their own; what looks like timidity in the deer and ferocity in the lion were assumed to mirror their own feelings: if a deer ran away, it was because of fear; if a lion attacked, it was because it was enraged. The animistic sources of religious beliefs remain apparent in some of the earliest-known efforts to form theoretical explanations of the world. The Presocratic philosopher Thales, for example, hypothesized that 'everything is full of souls' – by 'soul' he meant an animating principle – to explain such phenomena as the magnet's ability to attract iron.[1]

History tells us that these kinds of 'knowledge what' explanations consisted principally in what we now call 'religious' beliefs. These in turn contributed further kinds of supposed 'knowledge how' by suggesting forms of interaction with aspects of nature, or the agencies that control nature, hoping to influence or propitiate them through ritual, prayer, and sacrifice. It is an interesting speculation that, as liturgical (religious, ritualistic) means of influencing nature came to be displaced by more practical and mundane expertise, so the interest in effecting control transferred itself from nature to society; perhaps, as suggested by the concept of 'taboo', when controlling certain kinds of behaviour was no longer regarded as necessary for influencing nature or nature's gods, the social control – in the form of conceptions of 'morality' – endured. Whether or not this is the case, the main point remains that until very recently in human history 'knowledge how' has been far in advance of 'knowledge what', and the effort to provide the latter has until very recently rested chiefly on imagination, fancy, fear, and wishful thinking.

As suggested by reference to Thales above, the story of humankind's efforts to 'know what' in addition to 'how', but without relying on imagination and traditional beliefs, first comes fully into view with the philosophers of Greek classical antiquity from the sixth century BCE onwards. Thales, who flourished around 585 BCE in Ionia on the east coast of the Aegean, is often cited as 'the first philosopher', because he is the first person known to have asked and answered a question about the nature and source of reality without recourse to myth. In desiring a more intellectually plausible account than was offered by mythographers and poets, he sought to identify the cosmos's *arche* ('principle'), defined by Aristotle as 'that of which all existing things are composed ... the element and principle of the things that are', by working it out from what he saw around him. His choice of candidate for the *arche* was: *water*. His thinking can be reconstructed as follows. Water is everywhere, and it is essential. It is in the sea, it falls from the sky, it runs in your veins, plants contain it, all living things die without it. Water can even be said to produce earth itself; look at the vast quantities of soil disgorged by the Nile in its annual floods. And as the clincher: water is the only substance Thales knew that can occupy all three material states of solid (when frozen), liquid (the basic state), and gas (when boiling away as steam). So, it is ubiquitous, essential, productive, and metamorphic; it is the only thing he knew to be so; it must therefore be the substance from which all other things come and on which they depend: the *arche* of the universe.[2]

This is ingenious thinking, in the context of the time. But the really important point about it is that it relies on *observation and reason alone*, not on myths, legends, or imagination. This is why Thales is nominated as the first philosopher. No doubt plenty of other people thought in similar ways before him, but we have no record of them. As a result we identify him as the first figure in a new phase of history, for whereas *technology* – 'knowledge how' – had been in development for millions of years, *science* – 'knowledge what' – began at that moment.

Note, however, that observation and reason require a context of enquiry, and an accumulation of results corrected by tests. They are not enough just by themselves. Observation and reason gave our ancestors the view that the Sun moves across the sky, for indeed it appears to move – that is the observation we make – and everything on the Earth around us remains still. Therefore the reasonable conclusion is that the Sun is the mobile object, not the Earth. We think the same about the Moon and for the same reason, and in that case we are right. It took repeated and deeper applications of observation and reason to arrive at the counterintuitive result that it is the Earth that moves relative to the Sun, not the other way round.

This is one indication of the general point that the history of 'knowledge what' started slowly, increasing falteringly until a body of context and test had built up – and also because it was too often opposed by powerful traditionalist interests, principally religious, that felt threatened by it. It began its swiftest climb only at the beginning of modern history, in the sixteenth and seventeenth centuries.[3] Since the nineteenth century, however, the growth of 'knowledge what' has been meteoric.

But note that this knowledge is still growing, is still in an incomplete state; perhaps much of it is in a very early state, and perhaps some of it will be adjusted, corrected or discarded as evidence accumulates and the methods and technologies of enquiry continue to improve, which they do all the time. The questions about our world and ourselves that the explosive growth in knowledge *so far* make us ask can therefore only suggest tentative answers – though the human hunger for answers will seek them regardless.

In asking 'What do we know?', we are naturally led to ask, 'How do we know it?' and 'Are there limits to what can be known?' These questions involve others: what do we mean by 'knowledge' in contrast to 'belief' and 'opinion'; and, if there is a strict definition of 'knowledge' that makes a sharp contrast with 'mere' belief and opinion, are we not forced to ask, 'Isn't it belief, rather than knowledge *as such*, that we have? For if we define "knowledge" very strictly as *what is true and accepted on indubitable grounds*, is knowledge even possible at all – for what is there outside mathematics that is indubitable?' Some preliminaries help to sort through this set of important questions, and a quick way to do so is as follows.

One of the central areas of philosophy is *epistemology*, or 'theory of knowledge'.[4] A pointed way of carrying out this task is to show how we can respond to sceptical challenges to our claims to knowledge. In philosophy's technical debates about this matter, very simple knowledge claims such as 'I know that there is a laptop in front of me now', and very abstruse possibilities of being wrong when we make such claims, such as 'I could be dreaming or hallucinating; how can I rule out that possibility?', are the staples of epistemology. This makes us ask, 'Do we know *anything*? Can we *know* anything?' If the simplest and most direct claims to know something cannot be defended against sceptical challenges, even of the most *outré* kinds, then – obviously – we have a problem.

And, as it happens, we do indeed have a problem. It might be that what we learn from sceptical challenges, however bizarre they seem (like Descartes's 'I might be deluded by an evil demon' example, which he used in a purely heuristic way – that is, as a merely enabling device – to explore whether we can know anything *with certainty*), is that in the strictest sense we do not in fact know anything, at least outside mathematics and logic, which are the only enquiries where certainty is attainable.[5] This means that instead of *knowledge* in the strict sense, we have to accept that the best we can achieve is *highly credible and well-supported belief*; and correlatively that any of our beliefs, however powerfully supported by our best evidence, could turn out to be wrong.

This is exactly the view that science is based upon. Science recognizes itself as *defeasible*, that is, as subject to adjustment or revision in the light of new evidence if that new evidence calls current theory into question. Science is arguably humanity's greatest intellectual achievement; the scientific method is the paradigm of responsible, careful, scrupulous investigation into its various subject-matters, and it is acutely self-critical and controlled by the empirical data of experiment – which is to say, by the way the world is and not by how we wish it to be. In line with this deep sense of epistemological responsibility, scientists do not claim to *know*, but they do ensure that their theories are secured to the utmost degree by rigorous testing and evaluation. It is standard practice in high-energy physics experiments, for example, not to publish a result unless it achieves the degree of confidence known as 5-sigma, that is, that the chance that the results achieved over the course of all the experimental runs amount merely to a statistical fluctuation is only 1 in 3.5 million. The journal *Physical Review Letters* regards 5-sigma results as 'discoveries'.

This kind of intellectual responsibility characterizes all serious enquiry, in history and the social sciences as well as the natural sciences. Techniques and methodologies may vary according to the subject-matter being studied, but the *ethics* of enquiry apply to them all, not least in dealing with the problems that all forms of enquiry encounter, and that I will describe shortly.

Note that *scientism* – the view that science can and will ultimately explain everything – is not the same thing as science. Particle physics does not pretend to explain political systems; inorganic chemistry does not pretend to explain the qualities of Romantic poetry. Science is subject-specific – its researches are individually focused on the fundamental structure of matter, the evolution of biological species, the nature of distant galaxies, the development of vaccines against viral infections, and so on. It is an acutely self-aware enterprise, governed always by the scrutiny to which scientists subject their own and others' work long before venturing to publish it.[6] Its example is general. History, along with other social sciences and the humanities, offers more commentary on society and the human condition, but the same considerations about intellectual integrity apply.

These considerations oblige us to confront the problems – sceptical ones, methodological ones, cautionary ones – that beset enquiry, and that are brought more clearly to mind by the recent dramatic advances in knowledge precisely because of the extent of ignorance they reveal. I identify a dozen such, and raise them in their relevant places in the discussions to follow. I name as follows:

The Pinhole Problem. Our starting point in all our enquiries is the very limited and highly circumscribed data available to us locally in space and time, and, from our finite point of view, allowing us a view of the universe and the past as if through a pinhole positioned at just our restricted scale. Do our methods successfully carry us through and beyond the pinhole?

The Metaphor Problem. What metaphors and analogies are invoked to make sense of what these enquiries are telling us, and might they mislead?

The Map Problem. What is the relation between theories and the realities they address, given the analogous differences between a map and the country of which it is a map?

The Criteria Problem. What are the justifications and, where necessary, correctives for the application of criteria such as 'simplicity', 'optimality', even 'beauty' and 'elegance', in the formulation of research programmes and approval of results? Do appeals to these 'extra-theoretical criteria' help or distort enquiry?

The Truth Problem. Given that empirical enquiry gives us defeasible probabilities, what are the standards (such as the sigma scale in science) that can be regarded as satisfactory short of certainty? Does this imply that we have to treat the concept of truth pragmatically, as a (possibly unattainable) goal of enquiry upon which, in the ideal, enquiry strategically converges? Where does this leave the concept of 'truth' itself?

The Ptolemy Problem. Ptolemy's geocentric model of the universe 'worked' in a number of ways, permitting the successful navigation of the oceans and prediction of eclipses, thus showing that a theory can be efficacious in some respects while still being incorrect. How do we avoid being misled by pragmatic adequacy?

The Hammer Problem. Summed up pithily as 'If your only tool is a hammer, everything looks like a nail', this reminds us that we tend only to see what our methods and equipment are capable of revealing to us.

The Lamplight Problem. One searches for one's lost keys under the street lamp at night, because it is the only place where one can see. We enquire into what is accessible to enquiry, for the obvious reason that we cannot access what is inaccessible.

The Meddler Problem. Investigating and observing can affect what is being investigated or observed. When one studies animals in the wild, is one studying them as they would be if unobserved, or is one studying behaviour influenced by their being observed? This, accordingly, is known as the 'Observer Effect'. Can the disruption caused by slicing and staining a specimen for microscopic examination be reliably excluded? Can smashing subatomic particles reliably reveal how they formed in the first place?

The Reading-in Problem. A problem mainly for history and the psychological sciences, in which interpretations of data are often made according to assumptions local in time and experience to the investigators. Can we guard against this as a source of distortion?

The Parmenides Problem. The danger implicit in *reductionism*: reducing everything to a single ultimate causal or explanatory principle, which on the face of it looks like the worst kind of elementary mistake, but which, remarkably, is a characteristic of hard science.

And, finally, *the Closure Problem.* The desire to reach a conclusion, to have a completed explanation or story, to tidy up and sign off. It is a natural human impulse to have satisfying narrative explanations, 'this because that' where 'that' does the job of terminating the explanatory chain, closing down the need for a further 'that'. Putative explanations of the 'god of the gaps' kind provide classic examples. But so does what is implicit in the Parmenides Problem.

The three areas of enquiry canvassed in the pages to follow are affected by various of these problems with different degrees of force. I discuss the most salient of them in each area, and in the Conclusion.

These problems make some thinkers say that there are things we can never know. They say, for example, that questions about the nature of consciousness will never be answered because trying to answer them is like an eye trying to see itself. This is a counsel of despair that no enquirer should accept. If the question 'Are there limits to knowledge?' is meaningful, it is at best a defeatist one in implying that there might be such limits. But it is not a meaningful question, because it is not an answerable one – it could only, *per impossibile*, be answered when we reach the contradictory position of transcending the limits of knowledge and being able to look back at them to see where they lie. So the agnoiological ('cannot know') position is untenable as a general theory of enquiry and its aims. Instead, a commitment to the unlimited possibilities of knowledge is key; it is what motivates us in the continuing search for greater understanding of the universe and ourselves. But we learn from a consideration of the Pinhole Problem and the others how we should enquire, what we must avoid or take into account; we learn what we must do to try to advance knowledge and diminish ignorance, given the challenges that face the endeavour.

This book is not about epistemology in the narrow philosophical sense of answering sceptical challenges to our most basic knowledge-claims in an effort to see what can be known on the *strictest* definition of 'knowledge' as *what is true and accepted on indubitable grounds*. Instead it is about exploring and understanding, in a broader philosophical sense, the *highly credible and well-supported beliefs* that we *informally* call 'knowledge'. Indeed from now on I shall use the term 'knowledge' in this latter sense, which in any case is its mainstream sense: it is the sense of 'knowledge' in which what encyclopaedias contain is 'knowledge'. And it is about knowledge and ignorance, in this sense, regarding the science, history, and psychology we have so recently learned.

I ask the following questions about these fields of enquiry. What do we know in these areas of enquiry, and what did we once think we knew? How do we know it now, and are there any questions that arise, or reservations we might have, about the claims, methods, and assumptions at work in this knowledge and its acquisition? One of the constructive tasks of philosophy is the conceptual housekeeping it can offer by the kinds of questions it asks, a task described by John Locke in his *Essay Concerning Human Understanding* – written in support of the burgeoning genius of seventeenth-century science – as that of an 'underlabourer' helping to clear the path along which enquiry progresses. In the general sense of philosophy as reflection and the quest for understanding, this metaphor is apt as a description of the task here.

The three areas of enquiry canvassed in the following pages – the world, the past, and the mind – are: (Part I) particle physics and cosmology; (Part II) history, archaeology, and palaeoanthropology; and (Part III) the investigations of mind and brain in neuroscience and cognitive neuroscience. It is not, of course, possible to be comprehensive; I focus on central aspects of each field.

These are not the only new and recent areas of knowledge that have appeared and grown with dizzying rapidity in recent times, but they are arguably the ones that make the greatest difference to our self-understanding. In another time and place one would add areas of science that are destined to have a major effect on the future of humanity in their different ways. One is gene therapy, 'genetic engineering' (as benignly envisaged to protect, for example, against inherited disease), and applications of stem cell research in medical science. These developments are imminent but not yet fully arrived, and their impact highly speculative; one can hope that they will bring benefits in relation to many of the diseases that plague humanity now that lifespans are so much longer – cardiovascular disease and the cancers chief among them – and to ageing itself. But very little thought has yet been given to the social, psychological, and economic impacts of lives even longer and much healthier than now.

The other set of developments destined to affect the future of humanity relates to artificial intelligence and its applications. Perhaps saying that these developments will affect the future is already out of date: AI is here and already at work in many ways, most of them beneficial. How far the developments will go and what their combined effect will be are questions currently open for debate.[7]

'Recent' is the significant word in connection with the three areas of enquiry I consider here. Only think: the first observation of a subatomic particle occurred in 1897, when J. J. Thomson discovered the electron. The atomic nucleus was first described in 1909 by Hans Geiger and Ernest Marsden working in Ernest Rutherford's laboratory. Einstein's Special Theory of Relativity was published in 1905, his General Theory in 1915. Quantum theory developed in the first decades of the twentieth century, receiving a form of official endorsement by physicists at the Solvay Conference of 1927; the photon had received its name just the year before. The 'Standard Model' of the atom had become widely accepted by the 1970s, and confirmation that the Higgs field exists completed the model in July 2012.

It was not until the work of Edwin Hubble in the 1920s that the Milky Way Galaxy in which our solar system is located was recognized as just one of a vast number of galaxies, and not, as previously thought, itself the entire universe. That was in 1924; in 1929 Hubble observed that the universe is expanding. That led to the formulation of the 'Big Bang Theory'; in 1992 NASA's Cosmic Background Explorer (COBE) confirmed the existence of the background radiation left over from the Big Bang, now calculated to have occurred 13.72 billion years ago.[8]

Intimations and hypotheses that led to these discoveries existed beforehand, of course: ancient Greek philosophers had suggested that matter must be made of smallest parts (which is what 'atom' means – indivisible, uncuttable); seventeenth-century thinkers such as Pierre Gassendi and Robert Boyle speculated about *corpuscles* ('little bodies') as the constituents of matter and gases; and on an even more secure observational basis John Dalton and Robert Brown suggested the same in the nineteenth century. The philosopher Immanuel Kant proposed in the eighteenth century that the universe is expanding; as an originator of the 'Kant–Laplace Nebular Hypothesis' he has credentials in the field. And none of the work of Thomson, Rutherford, Einstein, and their successors in twentieth-century science could have been possible without such predecessors as Galileo, Newton, Faraday, Maxwell, and others. But it remains that by far the greater part of physics and cosmology as we now have them is of very recent date; the advances have all been made in the course of the last hundred years.

Yet the most amazing thing about this growth of knowledge is that it has revealed to us that we have access only to about 5 per cent of physical reality. It is less than a century since humanity arrived at a disciplined, evidenced view of the history of the universe itself from the Big Bang to the present – an immense achievement – but already the puzzles are prompting more exotic possibilities: that the universe is only one among many universes, or one phase in an unimaginable set of universal histories, or just the best explanation from a limited virtual-reality construct from our pinhole perspective on reality – these promptings courtesy of the hypothesized existence of *dark matter* and *dark energy*, and the highly speculative nature of suggestions about how relativity theory and quantum theory might be unified.

A different set of problems besets our knowledge of the deeper historical past. There has always been fairly extensive knowledge of classical antiquity and what has followed it up to the present day, because classical antiquity itself has survived to us, both in physical remains and in some of its literature, in a continuous line from its own time until now.[9] But all that was known in addition was suppositious knowledge of an earlier past, in the Homeric poems and in the histories and legends of the Hebrew bible (Christianity's 'Old Testament'). The latter purported to stretch history back to the creation of the universe about six thousand years prior to the period when the Old Testament histories were formulated. In those writings reference to the pharaohs of Egypt, Ur of the Chaldees, the empire of Babylon, and other places and features hinting at a past remoter than the classical period, together with their associated legends and myths, kept alive a sense of deeper historical time than was positively known about. Renaissance collectors of antiquities and curiosities stimulated interest by their activities in what lay beyond the pale of familiar history, but it was chiefly from the late eighteenth and – mainly – nineteenth centuries that more systematic efforts to dig into that deeper historical past began; quite literally so, in the form of archaeology. And only then did that deeper past start to come into view.

When Napoleon invaded Egypt in 1798, he took with him two hundred scholars to study that country's topography, botany, zoology, mineralogy, society, economy, and history. The temples and monuments of Luxor, Dendera, Philae, and the Valley of the Kings were measured and drawn. Within a decade the findings of the scholars began to be published in the first volumes of what became, by 1828, the encyclopaedic twenty-three-volume *Description d'Égypte*, unleashing an international mania of interest in all things Egyptian and by extension Levantine. Translation of the hieroglyphic inscriptions on the Rosetta Stone was painstakingly begun by a number of scholars, the breakthrough coming in the early 1820s when Jean-François Champollion successfully identified some of the language's phonetics by means of the names figuring within cartouches both in the Rosetta Stone inscriptions and in other sources such as the Philae Obelisk.

A rapidly increasing interest in digging up the past, in the literal archaeological sense, seized a number of nineteenth-century amateurs. A significant part of the motivation for some was to find confirmation of Old Testament history; for others it was the search for curios and collectibles; for thieves alerted by the amateurs' interest it was profit. The first major site discovered in Mesopotamia, Nineveh, was a trigger for the two latter kinds of activity. Paul-Émile Botta, France's Consul General at Mosul, made some excavations of a mound on the east bank of the Tigris and uncovered significant-looking structures. They later turned out to be the palace of Sargon II. That was in 1842; five years later a young British diplomat called Austen Layard set to work on the mound with a view to collecting as many objects of artistic or historical interest as he could find, ‘at the least possible outlay of time and money’, as he put it. But it was an Homeric impulse that led to the century’s best-publicized excavation: Heinrich Schliemann’s dig for the city of Troy, beginning in 1870. This famous endeavour did far more harm than good, because of the destructive methods Schliemann employed, cutting a huge crude slice into the many layers of archaeology at the Hissarlik site, and because of the over-ambitious claims he made about his findings there and at Mycenae later in the 1870s. His insensitive archaeological methods were alas par for the course with his predecessors and most of his contemporaries; they did much harm to fragile sites, annihilating evidence that time itself had not been able to efface.

In the succeeding decades a vastly more careful and systematic approach to archaeology began, among other things bringing the early civilizations of the Near East into sharper and more copious view. As the twentieth century progressed, so did archaeological methods and the contributions to them of science. Radiocarbon dating began in the 1940s, followed by advances in geochemistry and geophysics, with various forms of remote sensing including radar and lidar, 3-D laser scanning, aerial archaeology, Raman spectrometry, portable X-ray fluorescence, medical analyses of teeth and bones and examination of ancient DNA, forensic examination of the treasure-house of information in ancient middens and toilets, and more – all greatly enhancing the investigative capacities of archaeology. These developments have not been uncontroversial: debate over ‘processual’ and ‘post-processual’ methodologies and tensions between scientific and humanistic approaches in archaeology continue, even as archaeology progressively strips away more layers of past time and adds more layers of understanding.

Major mysteries remain. What caused the collapse of Bronze Age civilization in the period around 1200 BCE, plunging what had been the highly advanced civilizations of the eastern Mediterranean and Near East into a ‘Dark Age’ of several centuries? Egyptian records blamed successive invasions by an unknown group described as the ‘Sea Peoples’, but historians largely agree that the causal factors were much more complicated – among them climate change, famine, and breakdown of the complex trade routes running from as far east as the Indus Valley to as far west as Britain. That Dark Age drew a blind across the past until archaeology removed it; it is remarkable to think that the impressive architecture and exquisite art of Mesopotamia, the Levant, the Aegean, and Egypt were almost completely unknown until so recently.

But these discoveries relate only to the last six thousand years or so, although also offering some routes into the twelve thousand years since the inception of the Neolithic Period, when systematic agriculture and urbanization began. Before that the history of *Homo sapiens* and its relatives and predecessors tails evermore thinly and ambiguously into a complex and vastly remote past. Science has been a major boost here too, but, although assiduous searching has brought increasing amounts of evidence into palaeoanthropology and anthropogeny, what it tells us about human origins grows evermore tantalizingly inconclusive; every new discovery of teeth, bones, and tools seems to complicate rather than clarify the picture of our deep ancestral past. An example is the remarkable discovery in South Africa, less than a decade before these words were written, of *Homo naledi*, whose puzzling mixture of characteristics – its primitive head, upper body, hips, and curved fingers – are reminiscent of australopithecines, which lived on either side of 3 million years ago, but its advanced hands and feet are similar to Neanderthals and modern humans. Meticulous dating of the remains produced the astonishing result that *naledi* is recent, living about three hundred thousand years ago, which makes it contemporary with early-modern *Homo* and itself a member of the *Homo* clade.

It is no surprise that the largest and smallest scales of the universe, and the buried past both of civilization and our species, should present the investigative challenges they do. What is striking is how vividly they present that evermore familiar and challenging paradox of knowledge: *the more we know, the greater the extent of our ignorance becomes apparent.* But what of the third area of enquiry, brain science and psychology? Knowledge of ourselves, our minds, consciousness, human nature – is this not something we are intimately close to, and obsessively interested in, as our literature, entertainment, gossip, meditation, anxieties, hopes, loves, dreams, and fears unremittingly tell us? And yet even here the paradox is repeated, of an explosion of knowledge creating yet deeper mystery. For all the devotion given by philosophy, art, literature and our other self-reflective endeavours to the question of who and what we are, we still do not fully understand – even, perhaps, yet half understand – human nature and psychology, still less the complex material reality that underlies them, namely, the brain.

It is a matter of mere decades since it became possible to view brain activity non-invasively and in real time to try to correlate areas of the brain with functional and psychological capacities by means of *functional* magnetic resonance imaging, 'fMRI'. Prior to the advent of fMRI as a neuropsychological tool, most reliance had to be placed on 'lesion studies', matching injury or disease in parts of the brain to loss or disruption of such various functions as speech, movement, vision, hearing, memory, and emotional control. Brain research has an important practical application to the task of finding ways of repairing damaged brains, preventing or reversing dementias, and curing epilepsy. For obvious reasons these tasks go hand in hand with understanding the brain localization of mental capacities. But brain studies by themselves might not say everything we wish to know about human nature and psychology. Evolutionary psychology, and its more inclusive forerunner sociobiology, offer perspectives in these respects – controversially, as indeed is the case with neuropsychology too; for both sciences are nascent, their methods and equipment still in development, the opposing weight of traditional views and beliefs still great.

The intractable nature of human psychological material poses a formidable challenge to understanding it. But that is not the only barrier facing enquiry: there is anxiety too, fears that a Pandora's box might here be opened – in the worst case, as conceived by science-fiction writers who, either alarmingly or helpfully, have a propensity to identify thought-provoking scenarios, including the following: chips implanted in the brain to control behaviour and thought, the complete invasion of privacy this could be imagined to involve, the usurpation of humanity by artificial intelligence incorporated into what, by comparison, is the Model T Ford of the evolved primate brain, which the Ferrari of intelligence technologies might overwhelm; and more.

What we know matters a great deal, obviously. It might seem to matter less that we understand why the Bronze Age Collapse occurred three thousand years ago than to understand the structure and function of the brain, because this latter guides us in treating its diseases and injuries. The former may seem a matter of mere curiosity, though in fact it could teach valuable lessons, to anyone wishing to learn them, about the factors that lead to economic and social problems, even to civilizational catastrophe, as has happened more than once in recorded time. As this shows, all knowledge is useful and much of it is vital.

But it also matters that we understand *how we know.* When we see how scientific and historical knowledge is acquired, what problems are overcome in acquiring it, and what questions are raised about the assumptions and methods involved, we not only learn how to evaluate what we know, but we also learn a great deal about responsible thinking and the demands of intellectual honesty. These things matter in every sphere of human activity, and they are at a premium. The arts of persuasion, of redirecting attention, of magnifying or masking facts, of influencing and manipulating opinion, are commonplace everywhere from politics to advertising – and they all rest on the truth that, as Bertrand Russell once remarked, 'Most people would rather die than think, and most people do.' For, alas, persuasion and manipulation are made to seem to matter far more than the effort to be truthful. Therefore to know about what we know and how we know it is a grand corrective to the virtual realities and semi-realities that are continually being flashed before our minds by partisan causes and agencies wishing to sell us something – a product, an idea, a policy, a lie.

The following discussions are arranged as follows. I begin with a survey of what *was* the frontier of knowledge in the process – not always linear or smooth – that led to the bodies of knowledge that are current, at this time of writing, in physics, ancient history, and studies of the brain and mind. I survey the main discoveries that have so recently been made in these regions of enquiry, and consider some of the questions, problems, and promises associated with each. As this is a book for the interested reader, no prior knowledge of these fields is assumed. Those with expertise in one of the fields might wish to go directly to the sections of the relevant part where questions and problems are discussed. Clarity and accuracy have been the goals throughout, but as each of these fields is an actively developing and vigorously contested domain, I do not expect that any of the views mentioned will command universal assent. But debate is a good thing; it is the motor that drives the wheels of progress.

Part I

SCIENCE

In plain sober truth, without overstatement, science is humanity's greatest intellectual achievement. 'Science' is a capacious term but clear enough: most people get some elementary physics, chemistry, and biology at school, but less familiar and far deeper are the parts and combinations of these broad domains and their subject-matters, which range from enquiry into the fundamental elements of physical reality, through the complexities of life, to the furthest reaches of the cosmos. In the very recent past these enquiries have burgeoned exponentially. The applications of many of these discoveries in technology and medicine have been, in the literal sense of both terms, revolutionary and transformative.

Yet it is still the case that the great majority of people on the planet know little about what the sciences have so far revealed, and they adhere to a picture of the world similar in many respects to the one that had been dominant before the scientific revolution of the sixteenth and seventeenth centuries CE. That world-view – of a deity-created universe centred upon mankind physically and morally – was functionally dominant then, but, although it is still the majority belief, it has become functionally marginal, for in almost all practical respects the world runs on science and technology.

Given the success of science, it is remarkable that, even as it progresses with such giant strides, it should at the same time more vividly exemplify the paradox of knowledge – that every gain in knowledge multiplies the sense of our ignorance. This is most true in fundamental physics and cosmology, less so in the biological and medical sciences, the latter in particular showing how in applied science the horizon of competence in controlling aspects of the world has advanced beyond the imagination of previous generations. I therefore focus on physics and cosmology in the following pages but add two ingredients: a sketch of the technological prehistory of science, and what might be described as a superposition of the structures of thought that shape scientific enquiry, to illustrate that assumptions concerning 'what the world must be like', and what shape a satisfactory explanation of it should take, are surprisingly persistent features of our sense of reality and might explain some of the perplexities generated by science's very successes.

developed. It has been calculated that hundreds of hours of experience are required for the manufacture and expert use of Acheulean-level artefacts. Laziness is the easier option, encouraging adherence to a familiar technology if it does the job more or less satisfactorily. Certainly the elegant, symmetrical, and diverse Acheulean tools required much higher levels of skill and planning than the Oldowan tools, and that speaks volumes about the development of their makers' minds.

Acheulean tools are fashioned from stones selected for their desirable fracture properties: chalcedony, jasper, and flint, and in some places quartzite. Suitable stones were transported considerable distances from where they were found to where the tool-makers camped, and the instruments made from them were worked into bifaced handaxes and cleavers. The tools display increasing elaboration over the 1.3 million years during which the industry flourished. Early handaxes were made by hitting them against a stone serving as an anvil; later on wooden hammers were used to produce smaller, more slender axes with sharper and straighter edges. There is evidence of hafting in the Acheulean industry; the wood of hafts does not survive, but traces of adhesive material such as bitumen and conifer resin are found on some axes and hammers, and, together with the impact marks they display, this suggests that they were wielded as tools with handles.

About 300 kya ('kya' is 'thousand years ago') tool-makers evolved the Levallois technique, characterized by careful preparation of cores. This involved taking a lump of stone and fashioning it into a tortoise-like shape, flat on the bottom and humped above; that is the core. A skilful blow on a selected striking point produces a flake that can be worked further, using bone, an antler tip or soft stone, to achieve the desired result. Use of this technique by Neanderthals characterizes the Mousterian stone industry, named for Le Moustier in France where examples were first found, though the technique was evident throughout much of Africa at the same period.

The development of Levallois techniques is contemporary with the appearance of 'anatomically modern humans' in Africa at about the same date of 300 kya. Around 100 kya art appears in the human record – the discoveries in Blombos Cave in South Africa provide some of the earliest evidence – and then, both in and outside Africa from about 60 to 50 kya, increasingly rapid technological changes began, leading to the Aurignacian tool industry from 40 kya onwards, typified by blades, burins, needles, and scrapers made from bone and antler as well as stone. Given that the Aurignacian is also characterized by cave art, sculpture (for outstanding examples, the Venus of Hohle Fels and the Lion-Man Figurine of Hohlenstein-Stadel), decorative items such as necklaces, and musical instruments (such as the bone flute also found at Hohle Fels), the tools made were not restricted to subsistence activities. These developments signify another large stride in the human story.

Before 12 kya microlithic tools – small sharp flakes fixed into a haft to serve as a saw or scythe – and polished tools made their appearance. Polishing stones by careful grinding improves their strength and effectiveness both as tools and weapons, making them less prone to fracture. It also doubtless enhanced their aesthetic qualities in the opinion of those who used them, as suggested by the fact that polished stone axes were included among other grave goods with their deceased owners.

Just how advanced human technology had become by the Neolithic Period – commencing 12 kya – can be inferred from Oetzi the Iceman, whose glacier-preserved body was discovered in the Alps in 1991. Although he lived much later, towards the end of the fourth millennium BCE, Oetzi's tools and equipment were little different from what would have been available at the beginning of the Neolithic, except in one respect: he had a copper-headed axe. Both his arrowheads and his dagger were made from knapped flint, he wore clothes made of different kinds of leather, and he had a bearskin cap with a leather chinstrap. His cloak was made of woven grass, and he had waterproof shoes with bearskin soles and uppers of stitched deer hide. His tool-kit included an awl or burin for punching holes in leather, scrapers, and flint flakes, and an instrument possibly for sharpening arrows. Some of the arrows in his quiver were fletched (had feathers fixed into the rear of the shaft for accuracy and stability in flight) and some not, suggesting that he made and repaired his equipment as he went along. He had been killed in some sort of fracas: an arrow was lodged in his left shoulder, and he probably died of blood loss because the wound is close to the site of an artery. His copper axe-head – Oetzi's period in history is known as the Chalcolithic, or Copper, Age, roughly 6.5 to 3.5 kya, the period immediately before the Bronze Age – was fixed to a yew handle with leather thongs. That is also how he secured his flint arrowheads to their shafts.

It is not so fanciful to image that one of Oetzi's ancestors at the beginning of the Neolithic Period might have been clothed and equipped much as he was; stone tools were still used in butchery in the Near East until around 1200 BCE, and throughout the Bronze Age flint daggers mimicked bronze daggers and vice versa, showing what it is anyway plausible to expect: that stone technologies and the development of metallurgy overlapped for a long time.

As interesting as tools themselves is what they say about their makers. The activities associated with more than 3 million years of tool-making are evidence of planning based on experience. Think of what that means: remembering, pondering, coming to a realization, experimenting repeatedly, making improvements – these are the deliberate and purposive applications of intelligence, and, even though the greater part of those three million years saw very slow development, the contrast between the worked stones of the Oldowan industry 2.6 mya and the use of stones to crack open nuts by some species of primates today is speaking.

Better tools made for more and better-quality food. For hominin evolution that meant keeping step with the increasing energy needs of bigger and more active brains. Indeed the relationship is reciprocal; it is a feedback loop involving a suite of adaptations – the intelligence to visualize a tool and then create it, with development of the associated manual dexterity, matched with the resulting increased quantity and quality of nutrition to fuel the whole process, input and output mutually fostering each other. Rising intelligence in the human lineage is therefore intimately connected with tool technology and the social and dietary advances it made possible.

A key development in much of this story is control of fire, which provided warmth, light, and safety from predators, and greatly increased the availability – because of digestibility and safety – of foods. Take the point about safety: the earliest of our ancestors who supplemented their diet of roots and fruits with animal food were almost certainly scavengers, making use of leftover carcasses once predators had taken their fill. There is much evidence of bone marrow being consumed, a highly nutritious food, and – more to the present point – safe to eat, because less likely to have rotted. Some meat might have been sun-dried or even preserved with salt before cooking became possible, and doubtless remained an option afterwards. But cooking the meat of carcasses makes it safe as well as more palatable; this is what all human meat-eaters do today with most meats, given that meat is the already-decaying flesh of dead animals.[2] Fire also aided our ancestors in tool-making, for example, by hardening the points of wooden spears, and by rendering certain types of stone easier to flake.

No doubt hominins profited from adventitious occurrences of wildfires whenever they could, but control of fire – being able to start one at will, to contain it in a space, and to transport it from place to place – is what really counted. Profiting from the aftermath of a forest fire would have revealed to our ancestors the benefits it conferred – roasted carcasses, more accessible and digestible tubers, for example – and today's chimpanzees are observed to make use of burned landscapes likewise. A gradual process of taking advantage of naturally occurring fires, preserving a fire for a period of time, and eventually discovering how to start one – all this signifies observation and mastery of an energy-source that could be dangerous if mishandled, but was powerful when governed. There is evidence dating from as early as 1.7 mya that *Homo erectus* made systematic use of fire; certainly anatomically modern *Homo* had inherited control of fire from before 200 kya, as evidenced by finds in South Africa at the Cave of Hearths in Limpopo Province and the Klasies River Mouth Caves in Eastern Cape Province.

All the fires detected at earlier and later sites could have been taken from wildfires by holding a branch in the flames, say. It is hard to find a secure date for the first systematic control of fire. But, even before that happened, the inclusion of fire among the resources of human ancestors made a big difference to them and therefore their descendants.

Empowered by the skills and capacities, not least social ones, entailed by tool-making and control of fire, humans had reached Australia by 40 kya and the Americas by 15 to 12 kya. Every clime had been colonized, demonstrating not just the colonizers' ingenuity but also their adaptability. The knowledge and skill required for a hunter-gatherer life had to be prodigious for them to establish themselves in environments as different as the Arctic and the Australian outback, and to flourish there. One of today's human beings unexpectedly teleported back to 40 kya would not last long, unless he or she had military-level survival training – and even then would be a tyro in comparison to the human ancestors at home in those times and places.

From the beginning of the Neolithic Period around 12 kya the story of technology enters a new phase. Agriculture and animal domestication, urbanization, engineering, metallurgy, the wheel, and writing are among the most salient of the developments in the period between 12 kya and 1200 BCE. It is a lengthy period in its own right, but next to nothing in comparison to the hundreds of thousands of years that had passed in the course of the developments described above.

One suggestion is that the choice made by some people to settle and farm in one place, instead of continuing to hunt and forage nomadically, was forced on them by circumstance, and in certain respects represented a retrograde step. For one thing, skeletal remains of farmers from the Early Neolithic Period show them to be less healthy than their hunter-gatherer contemporaries. For another, population increases in urban settlements led to further division of labour and more hierarchical social organization, representing a loss both of equality and liberty, and promoted communicable diseases. The circumstance in question may have been that populations were already growing, and competition over hunting grounds and foraging had increased the frequency of conflict between groups. Depletion of

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