Thinking about Life

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The History and Philosophy of Biology and Other Sciences

Springer

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ISBN 978-1-4020-8865-0 e-ISBN 978-1-4020-8866-7

Library of Congress Control Number: 2008933269

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

springer.com

Preface

Our previous book, *About Life*, concerned modern biology. We used our present-day understanding of cells to 'define' the living state, providing a basis for exploring several general-interest topics: the origin of life, extraterrestrial life, intelligence, and the possibility that humans are unique. The ideas we proposed in *About Life* were intended as starting-points for debate – we did not claim them as 'truth' – but the information on which they were based is currently accepted as 'scientific fact'.

What does that mean? What is 'scientific fact' and why is it accepted? What is *science* – and is biology like other sciences such as physics (except in subject matter)? The book you are now reading investigates these questions – and some related ones. Like *About Life*, it may particularly interest a reader who wishes to change career to biology and its related subdisciplines. In line with a recommendation by the British Association for the Advancement of Science – that the public should be given fuller information about the nature of science – we present the concepts underpinning biology and a survey of its historical and philosophical basis.

In the first chapter of *About Life* we defined science, provisionally, as *a way of satisfying our curiosity by formulating questions about what we observe and answering them dispassionately*, *without making value judgements*. That definition seemed adequate at the time, but it is easy to pick holes in it. For example, the word 'science' is used regularly in television programmes, magazines, websites and broadsheet newspapers, but it seems to be used in different senses. How can we interpret the word when its meaning varies?

For most people, most of the time, 'science' means knowledge of a certain sort[1]: a collection of facts and beliefs that helps us to explain and predict the observable world coherently. A science textbook is a repository of such knowledge. When you study science at school or university you learn some of it. But 'scientific knowledge'

[1] The Latin *scientia* is usually translated as 'knowledge'. Prior to about 1800, 'science' denoted knowledge and understanding in general; for instance, what are now loosely called 'the humanities' were called 'moral sciences'. In the late 17th and 18th centuries, what we *now* call 'science' was labelled 'natural philosophy'. The word 'scientist' was invented in the 1830s by William Whewell, first president of the British Association for the Advancement of Science, but was not widely accepted until well into the 20th century.

changes continuously. You only have to compare an old edition of a textbook with a recent one to see how much has had to be rewritten in the last 10–15 years.[2] Emerging techniques reveal new facts about the world and our way of thinking has to change to accommodate them. Indeed, many different factors influence the way in which science changes: political, economic, religious, and so on. Therefore, a 'scientific fact' – a 'scientific truth' – is not constant or absolute or 'eternal'. Historians of science can tell us how, and in part *why*, our understanding of nature has changed over time. If we are to understand what science is and in what sense it can claim to provide 'truth', we need to understand why it changes. Therefore, much of this book is about history: the traditions from which modern science evolved and the controversies that arose in the process. Our emphasis from Chapter 6 onwards is on the history of biology.

Practising scientists use the word 'science' to describe their day-to-day work: planning and performing experiments, making observations, recording data, interpreting results, deducing, predicting, speculating, and communicating their findings. Before you are entitled to participate in these activities you must pass a number of examinations and serve what amounts to an apprenticeship under the guidance of one or more established practitioners. You will find yourself facing a career structure with various pay scales and competing, often intensely, with similarly qualified people. A code of professional ethics (largely unspoken) helps to regulate this competition. It should also regulate other aspects of your behaviour; good scientists do not invent data or steal each other's results; and when appropriate, they consider their new ideas in relation to technology and public debate. Understood in this sense – what people called 'scientists' *do* – 'science' is a subject for sociologists.

However, when practising scientists are asked what 'science' is, they seldom answer in terms of their daily work or their ethics. More commonly they tell us that science is a special and distinctive way of thinking about the natural world, unmatched in the intricate detail, practical applicability or 'truth' of what it generates. But what exactly *is* this way of thinking? How is it 'distinctive'? And in what sense is the knowledge it produces 'true'? Most of those are questions for philosophers, but scientists should also consider them.

It is surprisingly difficult to pin down the relationships among the history, sociology and philosophy of science. Sociologists of science look at single frozen frames in the film of history. History illustrates and tests the arguments of philosophers. The history, philosophy and sociology of science are collectively labelled 'science studies', but they remain separate disciplines, each with its own methods and standards of quality. They are specialised subjects, though their domains overlap considerably. In this book, we shall adopt arguments and perspectives from each of them to suit our purposes, but we shall not go into details.

[2] A 'scientific fact' may be here today but gone tomorrow as new evidence gives us greater understanding and corrects mistaken notions.

Many of our colleagues, including some eminent ones, have a deep antipathy to 'science studies', which they think distorts our picture of science and its status as a uniquely reliable mode of knowledge.[3] They say that it damages the public image and therefore the funding of science. We understand this antipathy, but the best work in the science studies disciplines should not be dismissed lightly. We need it to answer our questions about what science is, and *why* it is, and to explore the similarities and differences between biology and other sciences. In order to study the thinking behind the science of biology – which includes the whole range of knowledge from early life forms to modern medicine – we have to consider how it arose, and to understand, as well as we can, the thought process and philosophies of the pioneers of modern thought.

Without such considerations, we cannot go on to explore the most controversial topics associated with biology and other sciences today: patenting of human genes, cloning, genetic modification of crops, the obliteration of habitats, the extinction of species, and so on. These are matters that concern everyone, and we all need to be able to discuss them rationally, from an informed standpoint. We offer this book in an effort to meet that need.

The bibliography comprises publications that expand on the ideas presented in the text or offer different perspectives: some are introductory and others are more advanced, but all should be accessible to the non-specialist reader. For particular points, we have relied on professional publications and old or classical works that may interest readers with specialist backgrounds; we have cited these in footnotes at appropriate points in the text rather than adding them to the bibliography.

The book has grown from many years of reading and discussion. Among the numerous colleagues with whom we have exchanged views during the past four decades, Larry Briskman, Jürgen Lawrenz, Christopher Longuet-Higgins, Colm Malone, Jacques Monod, Karl Popper, John Porteous, Lewis Wolpert and J. Z. Young have perhaps been particularly influential. We are also grateful to Lloyd Demetrius and Carolyn Fisher for their helpful criticisms of draft chapters.

May 2008

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[3] Academic 'disciplines' are artificial categories – labels attached to different parts of a spectrum of human activity. These labels enable us to understand broadly where each individual operates and from what basis their arguments are developed.

Contents

Preface v

1 What is Science? 1
What we Know 1
Scientific Knowledge 2
The Need to Understand Cause and Effect is Uniquely and Characteristically Human 3
What is Distinctive About Science? 5
Science is Naturalistic Not Supernaturalistic 5
Scientific Explanations Are Mechanistic 5
Scientific Ideas Are Expressed in 'Value-Neutral' Terms 6
Scientific Explanations Are General Rather than Particular 6
Scientific Explanations Tend towards 'Reductionism' 7
Scientific Explanations Seek to Be Comprehensive 7
Scientific Explanations Tend to Be Abstract and, where Possible, Mathematical 7
Science Aims to Be – and to Make Things – as Simple as Possible 7
Scientific Theories Must Be Logically Consistent 8
In Principle, Scientific Knowledge Is 'Public' 8
Scientific Knowledge Is Impersonal 8
Scientific Knowledge Is Inherently Progressive 9
Why Is Science Distinctive? 9
Science Originated and Flourished in a Particular Time and Place 9

2 Culture, Technology and Knowledge 13
Evolution of Beliefs in Civilised Cultures: A Hypothetical Scenario 14
Modern Science and Technology 17
Optical Instruments 17
The Boulton-Watt Steam Engine and the Discovery of Latent Heat 18
Electrical Power and the 'Second Industrial Revolution' 19
The Electron Microscope 19
The 'Science-Begets-Technology' Myth 20

Origins of Naturalistic Thought 20
Greek Naturalistic Thought Was Not Science 22

3 Classical Roots 25
Plato (c.427–c.347 BC) 25
Aristotle (384–322 BC) 26
Aristotle's Physics 28
Athens after Plato and Aristotle 30
Alexandria 30
Mystical and Religious Thought in Alexandria 32
The Dispersal and Reunion of Classical Learning 33

4 Mediaeval Views of the World 37
The Fostering of Knowledge in the Muslim World 37
Advances in Knowledge during the Islamic Golden Age 38
Averroës and Algazel 43
Contemporaneous Changes in Europe 45
The Power of the Church 46
The Universities and Scholasticism 47
Pro and Contra Aristotle 48
Albertus Magnus and Thomas Aquinas 49
Aristotelianism 52
Robert Grosseteste and Roger Bacon 53
William of Ockham (c.1282–c.1348) 54
The Black Death 54
The Decline of Islamic Pre-Eminence 55

5 The Scientific Revolution 57
The Continuing Scholastic Tradition 57
Buridan 57
Oresme 58
Nicholas of Cusa 59
The Mertonian Calculators 60
Wider Cultural Changes: Secularisation 61
The Renaissance 62
Changing Styles of Thought 63
The Demise of Aristotelianism 64
Nicolas Copernicus (1473–1543) 64
Tycho Brahé (1546–1601) 64
Johannes Kepler (1571–1630) 65
Giordano Bruno (1548–1600) and Galileo Galilei (1564–1642) 66
The Principle of Inertia 66
Pierre Gassendi (1592–1655) 67
Isaac Newton (1642–1727) 67
The Distinctiveness of Natural Philosophy 68

Invoking or Not Invoking God 70
Mechanism Instead of Teleology 70
Mathematical Reasoning 71
Inherent Progressiveness 71
Relationship to Technology 71
Science and Cultural Relativism 72
Taking Stock 72

6 The 'Scientific Revolution' in Biology 75
The Demise of Galenism 75
Galen's Account of Blood Movement 75
Anomalies in Galenism 76
The Discovery of Venous Valves 78
Parallelism with the Demise of Aristotelianism in Mechanics 78
Is There a General Process of Theory-Change in Science? 79
Harvey's Theory of the Circulation 80
Connections with the Revolution in Mechanics 80
Conceptions of Natural Philosophy 82
Harvey and Descartes 84
Implications of Harvey's Theory: Testing the Predictions 85
The Early Microscopists 86
The Historical and Philosophical Context of the Early Microscopists 88

7 Aristotle's Biology 89
Starting from Scratch 89
Historia Animalium 90
De Partibus Animalium 91
De Motu Animalium and De Incessu Animalium 92
De Generatione Animalium 93
De Anima 95
Aristotle, Harvey and Descartes 96
Biology after the Late 17th Century: Aristotle's Legacy 98

8 How Different Are Organisms from Inanimate Objects? 99
Organisms as Mechanisms 99
Locke: Classical Empiricism 101
The Enlightenment 102
Against Mechanism 103
Living and Non-Living Matter; 'Vital Force' 104
Helmont 105
Sylvius 105
Boyle 105
Stahl 106
Buffon 107
Casimir Medicus 107

Lavoisier 107
Dalton and Berzelius 108
Wöhler 108
Pasteur 109
Modern Beliefs about Living and Non-Living Matter 109
The Third Anti-Materialist Stance 110
Overview 111

9 Cell Theory and Experimental Physiology: New Ideas in a Changing Society 115
Hume: the Achilles Heel of Empiricism 115
Kant 116
The Romantic Reaction 118
Naturphilosophie 118
Goethe 119
Geoffroy Versus Cuvier 120
Müller 120
The Birth of Cell Biology 121
Mechanistic Materialism 123
An Alternative Tradition of Physiology 125
Implications for the Development of Biology 127

10 Embryos and Entelechy 129
Preformationism 130
Problems with Preformationism 132
Taxonomy and the Critique of Preformationism 132
Epigenesis Reborn 133
The Mammalian Ovum and the Growth of Descriptive Embryology 134
Haeckel and the Recapitulation Hypothesis 137
Cell Division and the Beginnings of Experimental Embryology 138
Preformation versus Epigenesis in a New Guise: Roux and Driesch 139
Fate and Competence 144

11 Spontaneous Generation 147
Redi's Experiments: Insects Are Not Spontaneously Generated 148
Intestinal Parasites 150
Spallanzani Versus Needham 152
Changing Fashions 154
Pasteur Versus Pouchet 155
Afterword: The Origin of Life 158

12 The Evolution of Darwinism 161
Evolutionary Ideas Prior to 1800 161
The Influence of Geology 162
Lamarck's Concept of Transformation 163
Influence of Lamarck 164

Charles Darwin (1809–1882) and the Natural Selection Model 167
The Character of Darwin's Theory 167
Formative Influences 169
The Argument of the Origin of Species 170
Application of the Natural Selection Model to Human Evolution 171
The Philosophical Context 172
Positivism 172
The Fate of Positivism 173
Acceptance of Evolutionary Theory and Natural Selection 174
The Age of the Earth 175
The Nature of Heredity 176

13 The Great Heredity Debate 177
Darwin's Account of Heredity 177
The Biometric School 178
The Weismann Barrier 179
Mendel 180
The Mutationist (Saltationist) School 183
The Great Heredity Debate 184
Chromosomes and Heredity 185
Sutton's Errors 187
Morgan and the Chromosomal Theory of Inheritance 188
Philosophical Problems and an Alternative Viewpoint 190

14 Evolutionary Theory Attains Maturity 193
Ronald Fisher (1890–1962) and the Foundation of Population Genetics 193
Fisher's Errors 195
Sewell Wright (1889–1988) 195
J. B. S. Haldane (1892–1964) 196
Julian Huxley (1887–1975) 197
The Synthetic Theory of Evolution 197
Dobzhansky: Theoretical Models Reconciled with Field Biology 197
Mayr: Lamarckian and Saltationist Ideas Eliminated; Evolution Reconciled with Taxonomy 197
Simpson and de Beer: Synthetic Theory Reconciled with Palaeontology and Embryology 198
The Main Principles of the Synthetic Theory 199
Biochemistry is Reconciled with the Synthetic Theory 199
Bacterial Genetics 202
The Molecular Basis of Heredity and Evolution 203
The Modern Theory of Evolution 205

15 The Problem of Purpose 207
Artefacts and Organisms: Another View of the Living State 208

The Ambiguity of 'Purpose' 209
Making Mechanistic Sense of Function-Statements 209
Further Analysis of Function-Statements 211
Goal-Seeking Behaviour 212
The Limits of Meaningful Teleology? 213

16 The Scientific Status of Biology 215
Can Biology Be 'Reduced' to Physics? 215
Matter, Energy, Information and Organisation 217
Matter 217
Energy 217
Information 218
Organisation 219
Summary 219
Theories in Physics and Biology 220
Cell Theory 221
Evolutionary Theory 221
The Historical Character of Evolutionary Theory 222
The Incompleteness of Biology 223
Biological Nature and Human Culture 224
Living with Uncertainty 226
Human Beings as Moral Agents 227
Biology, Humanity and World Problems 228

Appendix: Science and Philosophy 229
The Nature of Scientific Theories 230
Theory Structure and Theory Change 232
Experiments 233
Models 234

Bibliography 235

Name Index 245

Subject Index 251

Chapter 1
What is Science?

What we Know

Try making a list all the things you know. You will soon give up – the task would be endless. But even a partial list will show that you have different *kinds* of knowledge.

For example: you know that just now you are sitting down, or standing, or walking across the room. You know the furnishings and the colour of the paintwork. You know what music is playing on the radio. You know, perhaps, that it is a cool day outside but warm in the house, and that you are thirsty. These are immediate, direct *sensations*.

You went to Benidorm on holiday last summer. A friend told you an amusing story yesterday evening. You once fell downstairs when you were four years old. One of your secondary school teachers had a face like a terrapin. You know all these things because you have a *memory*, a gigantic store of past experiences. You remember them.

You know how to ride a bicycle, drive a car, boil an egg, write your name, hammer a nail into a wall. So your list of knowledge includes *skills* as well as immediate and remembered sensations, skills that you have learned and practised.

Two plus two equals four. Dogs bark when they are disturbed or excited. Acorns grow into oaks. Grass is green; water is wet. We turn our experience into *generalisations*, which make up much of our everyday knowledge. Generalisations tell us about patterns and regularities in the world, so we use them to *predict* future events. We also depend on them when we try to devise ways of *controlling* or *manipulating* events and objects.

You know that the Earth is round (more correctly, an 'oblate spheroid'), and that the climate is changing, and that uranium is mined and purified from ores – not because you have experienced or discovered those facts for yourself but because you have been told them by authorities you trust. We gain much of our knowledge by *learning*, usually indirectly, from the people who found it out. Many of our generalisations come from what we hear or read, not from direct experience.

We have moral knowledge (it is wrong to rob banks or set fire to the neighbours' dustbins). We know our family and friends (what they look like, the sound of their voices, how they dress, what work they do, their mannerisms, their attitudes and beliefs). And we have many other sorts of knowledge.

P.S. Agutter, D.N. Wheatley, *Thinking about Life*,

Few items on this fragmentary list of things-we-know have anything to do with science. So if science is 'knowledge', it must be a special sort of knowledge – but special in what ways?

Scientific Knowledge

At first sight, it is easier to identify ways in which science is *not* special.

Like the rest of what we know, much of it relies on sensory experience, immediate or remembered. We test scientific ideas by matching them against what we can perceive: if the idea fails to match the perception, we reject it. Many scientific 'perceptions' depend on instruments that – as it were – extend the range of what we can sense. Objects too small to see with our unaided eyes can be seen through a microscope. Radiation with wavelengths longer or shorter than light (infrared or ultraviolet, for example) cannot be perceived through our eyes or other senses, but it can be detected and measured by special instruments. 'Measured' is an important word here; whenever we can, we attach numbers to what we (directly or indirectly) perceive. So scientific knowledge includes things that we can perceive using instruments as well as our unaided senses, and – when possible – *measurements* of these things. Fundamentally, however, it depends on what we sense, just like our ordinary everyday knowledge.

It also includes generalisations. Indeed, *specific* statements about individual objects or events have limited value in science. We are mainly concerned with general statements, regular and recurrent patterns in what is perceived. Most of the scientific generalisations we accept are learned from other people's work. That is inevitable; we would never make progress if we had to rebuild scientific knowledge from scratch in each new generation. An important use of generalisations in science – learned or otherwise – is to predict future events; but as we have already said, that is also true of the rest of our knowledge.

Skills are involved, too. A scientist has to learn how to use specialist instruments and understand what they reveal, and must be able to execute experiments. (An experiment is an arrangement by which a particular object or event can be observed and measured without interference from the rest of the world.) But every tradesman makes skilled use of special equipment.

In all these respects, science is only *slightly* different from everyday knowledge. Reliance on perceptions, generalisations and skills hardly makes it 'special'. Science is interesting in the way it is organised (theories, hypotheses and experiments), but even this is not particularly special, as the following everyday analogy shows.

Suppose your car is not stopping as quickly as it should when you apply the brake. You ask why. Perhaps there is insufficient brake fluid; you check to make sure. If your guess was right, you top up the brake fluid. You then ask why the level was low – a leak in the system, perhaps? If your guess was wrong, you try another: maybe the brake linings are worn and need to be replaced. You check (or ask a mechanic to check).

What is happening during this sequence of observations, guesses and checks? First, at the outset, you have an organised understanding of car braking systems and how they work. This 'organised understanding' is what in science we call a *theory*. That may seem an odd use of the word 'theory' since it consists largely of matters of fact, but scientific theories *do* largely consist of matters of fact. Second, you see a problem (the car is not stopping as it should), ask a question about it (why is the car not stopping as it should?), and then use your organised understanding – your theory – to guess a plausible answer. In science, such a guess ('the level of brake fluid is low') is called a *hypothesis*. A hypothesis is a possible answer to a question; it must be consistent with your theory and – crucially – it must be *testable* (in this case, by checking the level of brake fluid). If the test proves your guess wrong, i.e. the hypothesis is *refuted*, you try another guess – an alternative hypothesis. If the test seems to confirm your guess, you ask a further question (why was the level of brake fluid low?), propose a further hypothesis consistent with the theory (a leak in the system), test it (by looking for the leak), and so on.

Although this failing-brakes analogy is much simpler than most scientific reasoning, it is the same in principle. A scientific investigation entails exactly the same steps: noticing something odd or interesting, asking questions about it, proposing hypotheses (i.e. guessing possible answers) in the context of the relevant theory, and testing the hypotheses. That is how science progresses.

Notice the *nature* of the hypotheses in our analogy. They link a possible *cause* (low brake fluid, worn brake linings) to an *effect* (impaired brake function). All scientific hypotheses have that character: they are provisional cause-effect relationships that seem plausible in the light of an accepted theory (organised existing knowledge).

Cause-effect reasoning is the foundation of our understanding of the world, not least our scientific understanding. It enables us to make predictions. It enables us to find ways of controlling and manipulating events and objects.

The Need to Understand Cause and Effect is Uniquely and Characteristically Human

Chimpanzees seem to have only a limited idea of cause and effect. They can use simple tools such as sticks to recover food that is out of reach, but given a selection of possible tools, they cannot decide which is best for the job. They can pile boxes on top of one another to obtain a food reward, but they never realise that if the floor is uneven the boxes will topple over. A young human child might make such a mistake but will quickly learn from it. Chimpanzees can master human language to some extent, but they do not seem to use language in the wild. Human children acquire language in the first few years of life. Language is crucial for our understanding, not least our ability to think in terms of cause and effect and to learn skills.

Humans are very closely related to chimpanzees but our mental capacities are qualitatively different. We can infer cause-effect relationships, predict events, and express them in language. Our capacity to acquire skills, too, is much superior to

that of other species. We touched on the question of human uniqueness in *About Life* – it may be rooted in our social nature and our bipedalism – but whatever the reasons, our mental and technological capacities are indisputably unique. We depend on those capacities throughout our lives and we prize them highly. They make us human.

Equipped with such capacities, our early ancestors must have found themselves in a world full of objects and events for which there were no evident causes: changes in the weather, the cycle of seasons, volcanoes, birth and death. When we cannot understand the world around us in terms of cause and effect, we do not know how to solve day-to-day problems and we cannot decide what actions to take. We find such uncertainty intolerable. So our ancestors *invented* explanations for mysterious events; they constructed theories. Those theories probably took the form of myths (explanatory stories). We cope poorly in the absence of some form or system of beliefs – we need to tell stories that purport to explain what happens around us and to us. The price of our uniqueness seems to be a *need* as well as an *ability* to explain causes and effects.

What sort of beliefs might our ancestors have formed? The only causal agents they knew from direct experience were animate. Humans and other animals could deliberately cause things to happen, but inanimate objects could not. So all unexplained events may have been attributed to animate, perhaps human-like and almost invariably invisible agencies, which might be appeased or rendered co-operative by appropriate rituals or sacrifices. Early human groups who adopted such a policy probably fared better than those who did not: it would have made for greater social cohesion and enabled them to cope practically with the uncertainties of an unpredictable and often hostile world. It would at least have reassured them. Belief of this primitive religious sort could therefore have become selectively advantageous for early humans.

If so, then we, their descendants, may have inherited a biological predisposition to tell ourselves stories that make sense of our lives and the world around us. Faced with serious uncertainties, mortal dangers or traumas, we tend to become more religious. People with strong religious beliefs often lead longer and healthier lives and deal more effectively with adversity than sceptics do. Belief seems to be *biologically necessary* for humans, and 'supernaturalistic' or religious belief seems to be the most biologically fundamental (and therefore much the most widespread) kind.

'Belief' in this context encompasses all the contents of our minds and memories: what we know and understand, how we explain, predict, inquire, and so on. It also includes the articles of faith on which our story-telling depends. Modern science, too, is founded on articles of faith, namely that the universe we observe is intrinsically orderly and that human minds are capable of grasping the essence of that order.[1] These are plausible *but untestable* premises.

[1] Einstein remarked that '*The eternal mystery of the world is its comprehensibility*'. But these two articles of faith have not been evident in all cultures.

What is Distinctive About Science?

The function of science is to make sense of the world so that we can answer questions, make predictions and control and manipulate events. But every human culture has its own ways of making sense of the world and of controlling and manipulating it. So what *is* different about science?

So far, we have found that scientific knowledge is broadly similar to everyday knowledge. Reading between the lines, however, we can begin to see distinctions.

Science is Naturalistic Not Supernaturalistic

Supernaturalistic belief, which we have argued is the most basic and widespread kind, differs from science. A supernaturalistic system seeks human, demonic or theistic causes for all events – diseases, for example. As scientists, we attribute diseases to infectious organisms, gene defects, environmental toxins and so on. The orbit of a planet and the progress of an avalanche are explained in terms of antecedent causes and theories of mechanics, not the dispositions and whims of gods. Science presupposes that *causes lie in the observable material world itself*. That distinguishes a 'scientific culture' from the overwhelming majority of human cultures.

Attempts to find naturalistic explanations date back to Classical Greece, which is why histories of western science traditionally begin with a glance at the Greek and Alexandrian philosophers. It is interesting to ask *why* naturalistic belief began in Greece two and a half millennia ago, and *why* the modern developed world has adopted it.

Scientific Explanations Are Mechanistic

Science explains events in terms of mechanisms. The cause must be a physical situation existing *before* the event, and it must have nothing to do with motives or intentions or purposes. If events are caused by conscious, animate, human-like agencies, then to explain the causes we must understand the motives – the purposes – of those agencies. If the causes are mechanistic, then it is misleading to consider motives and purposes because there *are* no motives and purposes. Events in the natural world have no intentions behind them.

You might suppose that if an explanation is naturalistic then it must be mechanistic as well. However, the world-view of the great Greek philosopher Aristotle was entirely naturalistic, but his explanations were deeply *teleological*, i.e. expressed in terms of purposes. As we shall see, the emergence of modern science, especially biology, entailed a long love-hate relationship with Aristotle's teachings.

It might seem impossible to eliminate teleology from biology because biological entities – parts of organisms – *do* have purposes. Nevertheless, modern biology is

a science; its explanations are as mechanistic as any in physics. This seeming paradox, and its resolution, will dominate much of this book after Chapter 7.

Scientific Ideas Are Expressed in 'Value-Neutral' Terms

In science, we do not evaluate things as good or bad, desirable or undesirable, beautiful or ugly, etc. We say what *is* the case and how it fits or fails to fit our existing theories. At least, that is the accepted ideal. Privately, we may (and often do) consider the result of an experiment good or bad depending on whether it is consistent or inconsistent with a favourite hypothesis. The hypothesis may have become a favourite because we find (or found) it aesthetically pleasing.

The claim that science is value-neutral is contentious; sociologists of science find compelling reasons to dismiss it. For example, what we actually choose to study, and the way in which we study it, may be determined largely by political, economic and other influences outside science. But any *particular* piece of scientific discourse is value-neutral, or should be.[2]

Scientific Explanations Are General Rather than Particular

Explanations in most cultures have tended to be particular rather than general. For example, the question was not 'What causes boils?' but 'Why has *this* person, or *this* group of people, been afflicted with boils at *this* particular time?' The answer was expressed in terms of particular practices and moral codes, or particular enmities. The cure would lie in countering a witch's power or appeasing an appropriate deity or practising some sort of incantation. Scientifically, we explain *all* cases of boils in terms of a common pathogenic agent. The cure lies in an antibiotic suitable for treating all cases of *Staphylococcus aureus* infection. The explanation is *general*.

[2] To see how contentious this matter can be, consider the following dilemma. All reasonable people consider racism to be morally unacceptable. However, many biologists (including psychologists) believe that human behaviour is mostly determined by our genes. That includes criminal behaviour. Now, it is well known that a disproportionate number of the inmates of American prisons are black. So it seems scientifically reasonable to infer that black Americans are genetically more predisposed to crime than white Americans. How do we handle this inference? We can decide either that the premise is wrong – i.e. that criminality is *not* significantly influenced by our genes – or that science compels us to be racist. If we choose the former alternative, we risk being accused of allowing values to influence our scientific judgment. (The authors of this book, incidentally, are willing to take that risk!)

Scientific Explanations Tend towards 'Reductionism'

In science, we usually try to explain large-scale phenomena in terms of smaller-scale parts. For instance, we seek to understand living bodies in terms of the cells they comprise, each cell in terms of its component molecules, and each molecule in terms of its atoms. The 'reductionist' approach helps us to explain things mechanistically and in the most general terms. Everything in the world is made up of the same small selection of atoms, in various combinations, so at the atomic scale everything must obey the same laws. The smaller the scale we observe, the more wide-ranging the phenomena. It is *large*-scale entities that are individual and particular.

Scientific Explanations Seek to Be Comprehensive

This 'reductionist' tendency helps us to find the most widely-applicable patterns of understanding (i.e. theories). Scientific theories aim at *comprehensiveness*, unifying our knowledge. We look for similarities underlying apparently *disparate* phenomena such as the falling of an apple and the motions of the planets – which would make no sense in most cultures. This is a hallmark of science. Like naturalism, a quest for comprehensive theories is evident in the work of the Greek philosophers, most obviously Aristotle. In contrast, other cultures tend not to seek general, widely-applicable theories; they are more concerned with the individual and particular and readily accept the *ad hoc*.

Scientific Explanations Tend to Be Abstract and, where Possible, Mathematical

Particular descriptions of objects and events are concrete and (usually) qualitative. We can only connect the falling of an apple with the motions of the planets when we focus on the *abstract* similarities between these events. Mathematics is a very effective way of expressing such abstractions precisely and deducing predictions from them. If we measure things rather than simply describing them – if we find out how *quickly* the apple falls – we can test those predictions critically.

Science Aims to Be – and to Make Things – as Simple as Possible

This claim may seem surprising, but it is true – provided you do not confuse 'simple' with 'concrete'. In science, redundant ideas are eliminated. The causes proposed

for any phenomenon are pared down to the bare minimum. *Parsimony* is a hallmark of a good theory, and of a good hypothesis: the simpler the suggested cause, the easier it is to test it unequivocally.

Scientific Theories Must Be Logically Consistent

Logical inconsistencies (self-contradictions) are eliminated by the abstraction and paring-down processes, but scientific explanations must also be *plausible* and *cogent*. They must be consistent with the rest of our beliefs – particularly with other scientific theories.

In Principle, Scientific Knowledge Is 'Public'

The means by which scientific explanations are established and tested must be *open to public scrutiny*, at least in principle. Divine inspiration and individual imagination are not acceptable criteria for belief, as they have been in many cultures. No matter how a scientific idea originates, which might indeed be a matter of individual imagination[3] (hunches), the observations, experiments and reasoning involved in testing it must be reproducible by anyone (provided he or she is appropriately qualified).

Scientific Knowledge Is Impersonal

For this reason, scientific writing is never couched in personal terms; it seeks to be *objective*. As scientists we write 'A causes B', 'Event X happens in such-and-such circumstances', 'Objects such as Y have such-and-such properties', and so on. We do not use 'I believe…' or 'I observed…', even though what we write about is the product of individual human senses and human thought. That is why scientific English is so peculiar: passive voice, few adjectives and adverbs, no rhetorical colour. It is dry and 'factual' – it would be difficult to read, largely devoid of charm, even without the formidable technical vocabulary. Individual personalities, and personal friendships and enmities, should not be allowed to influence science – though they sometimes do, e.g. in 'personal' remarks in scientific reports on research activities that are trying to establish new facts.

[3] Or a dream. Famously, the great organic chemist Kekulé solved the structure of benzene by means of a dream – but the 'dream-structure' then withstood critical experimental testing. It was the critical testing, not the dream, that made Kekulé's solution scientific and entitles us to believe it.

Scientific Knowledge Is Inherently Progressive

A scientific hypothesis must be tested, and when you test it you may make novel observations and discover new phenomena through your research work. The knowledge and beliefs that arise during the search for scientific explanations change over time. Most cultures undergo changes in their belief systems, largely as a result of contact with other cultures, but scientific knowledge is *inherently progressive and permanently provisional*. It is never intended to be as the Laws of the Medes and Persians – though it is often treated as though it were. What we know and believe now is not what we knew and believed in the past – and we will know and believe something different again in the future.

Why Is Science Distinctive?

In many general ways, science is just like everyday knowledge: it depends on sensory experience, memory, generalisations, skills and the search for cause-effect relationships. In other respects, it is unlike the systems of knowledge and belief in other cultures: it is naturalistic, mechanistic, value-neutral, general, reductionist, comprehensive, abstract, simple, logically coherent, 'public', impersonal and inherently progressive.

These distinctions are crucial. The findings of science seldom match intuition. Everyday knowledge does not tell us that the Earth orbits the Sun or that humans share half their genes with bananas, but science persuades us. Electrons, quasars and hormone receptors are not objects familiar from everyday life but they are familiar elements of scientific discourse. A way of producing knowledge that generates data so remote from sensory experience, and beliefs so contrary to intuition, is distinctly peculiar.

If science is such a peculiar sort of knowledge, so different from knowledge in other cultures, we would expect it to have arisen very infrequently during the course of human history, and only in particular locations.

That is a definite *prediction*. We can test it by examining the evidence.

Science Originated and Flourished in a Particular Time and Place

To find that evidence, look at the major topics covered in science textbooks (school or undergraduate level). For each topic, note the country and the century in which the basic ideas were established. Table 1.1 is an example. When the items in Table 1.1 are displayed on a map of the world (Fig. 1.1) and on a time-scale of human history (Fig. 1.2), the result corroborates our prediction – rather strikingly.

Table 1.1 Origins of some general topics in science

Topic	Country(ies) of origin	Century of origin
Human anatomy	Italy	16th
Heliocentric solar system	Poland	16th
	Italy, Czech Republic	17th
Geometrical optics	Holland, England	17th
Classical mechanics	Italy, France, England	17th
Biological microscopy	Holland, England, Italy	17th
Electrostatics	Italy	18th
Biological taxonomy	Sweden	18th
Electrodynamics	France, England	19th
Thermodynamics	England, Austria	19th
Electromagnetism	England, Scotland	19th
Atomic theory	England, Sweden	19th
Physical chemistry	Germany	19th
Organic chemistry	Germany, France	19th
Periodic table of elements	Russia	19th
Bacteriology	France, Germany	19th
Evolutionary theory	France, England	19th
Relativity theory	Switzerland	20th
Quantum mechanics	Germany	20th
'Big bang' theory of cosmology	USA	20th

Fig. 1.1 Outline map of the world showing the places of origin of the topics listed in Table 1.1

The inference is irresistible: all the topics that we regard as parts of 'science' had their roots in Europe (predominantly northern and western Europe) between the 16th and the 20th centuries – and apparently in no other place and at no other time.

You may wish to examine a different sample of topics. The result will be much the same, though if you choose disciplines of very recent origin then you might find

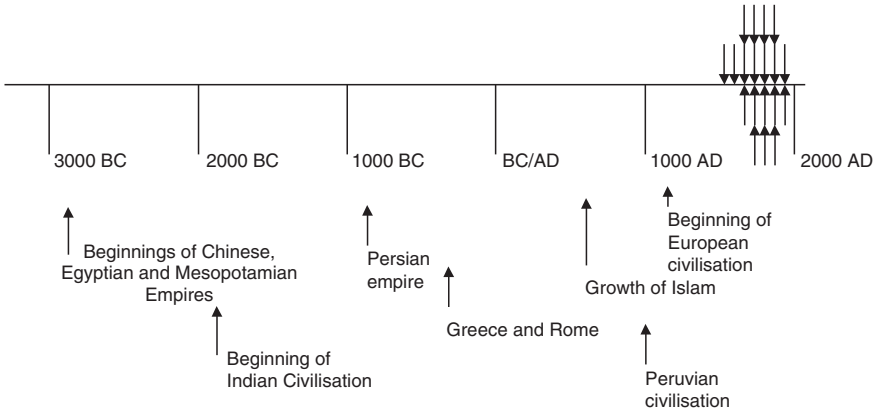

Fig. 1.2 Time-line of the history of human civilisation. The approximate dates of origin of major civilisations are shown in the lower part of the illustration. The arrows clustered above and below the extreme right of the time-line show the approximate dates of origin of the topics listed in Table 1.1

more of them appearing in North America or some other part of the developed world culturally rooted in European colonisation. None of the sets of ideas we now recognise as 'scientific' came from the great civilisations of ancient Egypt or Mesopotamia or India or China – though a great deal of knowledge from those civilisations came down to us via trade links. None of our modern scientific disciplines arose in Classical Greece or Rome, despite the naturalism of Greek thought and despite the great shaping influence that the Classical world exerted on later Islamic and European civilisation. There was nothing quite akin to modern science in Europe itself during the period 1100–1500, though European thinkers at that time had important insights into what we now call 'science'.

How can we account for this? Why did so curious and 'unnatural' a way of seeking knowledge as modern science arise in 16th and 17th century Europe, but apparently in no other place and at no other time in history? And why do we consider it more reliable than the more widespread (supernaturalistic,[4] specific, concrete) alternatives?

While we explore these questions, we should ask whether our data and reasoning are sound. Could appearances have deceived us? Was there, after all, a precedent for what we now call science?

[4] The word 'supernatural' is not used in modern science, though it remains extant in the vernacular. A scientist would qualify any mention of it by saying that it is a term used to describe a phenomenon that has yet to be explained rationally. One possible example is the alleged 'telepathy' between identical twins, the apparent ability to 'communicate' mentally over thousands of miles or behave simultaneously in very similar ways.

Chapter 2
Culture, Technology and Knowledge

We face three interrelated questions. First, is science uniquely the product of post-mediaeval Western Europe? Second, if not, where (and when) else did it arise – and why do we never hear about it? Third, if the naturalistic learning of Classical Greece was not science, how did it come to exert such a profound influence on the *emergence* of science in Europe 1,800 years or more afterwards? To tackle these questions, we first need to examine: (1) the relationship between knowledge or belief and culture, and (2) the routes by which Classical learning reached late mediaeval Europe.

Ways of knowing in all cultures share common features (sensory experience, memory, generalisation, mastery of skills, search for cause-effect relationships, etc.) because they are all human; but each is also distinctive. By definition, different cultures arise in different environments, each with its particular history. Tropical desert dwellers are unlikely to have knowledge and beliefs about polar bears or snow, but they are likely to know a good deal about sand, dehydration and scorpions. In the modern developed world, a hill farmer has different knowledge and beliefs from, say, a city accountant.

In other words, while humans are biologically predisposed to gain an understanding of the observable world, the *particular* beliefs they form and the *particular* knowledge they acquire depend on where and how they live. Can we say anything about the relationship between life-style and knowledge that will help us to understand why science arose when and where it did – what it was about post-mediaeval Western Europe that caused, or enabled, scientific thought to emerge?

Archaeologists and social anthropologists understand a lot about the differences among cultures, but they are reluctant to generalise. However, relatively little of their work concerns knowledge or beliefs (which in any case are not accessible to archaeologists, except where they are investigating a culture that left written records). Their focus is rather on technology: tools, weapons, what people wore and what they ate and what their homes were like. Appropriate tools, clothing, housing and methods for obtaining and preparing food are necessary for human survival, but what is 'appropriate' depends on the environment. Like knowledge and belief, it is culture-specific. When children are brought up, they learn about the technological artefacts of their community as well as information about the world around them. Children in our society, for example, acquire knowledge and beliefs about

P.S. Agutter, D.N. Wheatley, *Thinking about Life*,

televisions and computers as well as about the structure of the solar system and what genes are.

That raises another pertinent question: what is the relationship between science and technology – or, more generally, between knowledge or belief and technology? It is commonly assumed that, in our modern world, science gives rise to technology. In other words, the idea comes first and the application follows. In fact, however, knowledge and technology can be interconnected in quite complicated ways – or entirely unconnected.

Evolution of Beliefs in Civilised Cultures: A Hypothetical Scenario

The earliest civilisations[1] arose on the fertile flood-plains of great rivers, where sufficient food could be produced every year to support large, non-migratory populations. We know too little about the early history of any ancient culture to describe it in detail, so the following scenario follows no actual historical sequence. However, the pattern of development seems generally correct; the civilisations of ancient China, India, Mesopotamia and Egypt all had broadly similar characteristics. The same applies to Peru, where the immediate environs of the short but rich rivers were home to the earliest known indigenous civilisations of the Americas.

If a civilisation was to be viable, enough food had to be produced to support the large, concentrated populations of one or more cities. Therefore, appropriate times for preparing the land and sowing crops had to be decided. To make the right decisions, the annual flooding of the river had to be predicted. This required a calendar, which was necessarily based on observations of the stars, since the annual cycle of the heavens was the only reliable way of *measuring* – that all-important requirement – the passage of time. The existence of civilisation therefore presupposes an astronomically-based calendar.

The fact that such calendars worked reliably must have suggested a *causal* connection between particular configurations of stars and particular terrestrial events, especially the flooding of the river. How could such a connection be explained? The answer would have been couched in terms of deities associated with stars, planets, rivers, crops and so forth. But that would have led to another question: how could the *continuation* of this causal link – vital for the survival of the community – be ensured? Thus, the dawn of civilisation was inexorably linked to particular sets of knowledge, beliefs and practices. These included the names and natures of gods and the rituals appropriate for their worship and appeasement, as well as the study and interpretation of the night sky and the construction of calendars.

[1] Here we intend ‘civilisation’ in its literal sense, i.e. a community living in or centred on one or more cities.

No less important was social organisation. To ensure that sowing and harvesting were timed properly and conducted efficiently, a social hierarchy was needed. Civilised society needed leaders, just as it needed experts to interpret the heavens and mediate with gods. It certainly needed many labourers and someone to organise them. Kings, priests (kings usually being representatives of a priestly class) and numerous agricultural workers were inevitable concomitants of early civilisation.

Equally inevitable were improved tools for planting and harvesting and, in due course, for food warehousing and distribution. The better the tools, the bigger the harvest and the faster the population growth; and the bigger the harvest and the population, the greater the need for organised distribution. The dawn of civilisation had inescapable implications for technology and social organisation as well as for knowledge and beliefs.

It was natural[2] to generalise the causal link between celestial and terrestrial events: perhaps *all* significant terrestrial events were heralded by celestial ones. In particular, rare and dramatic celestial events such as comets and eclipses betokened rare and dramatic terrestrial occurrences such as the fall or birth of kingdoms. If so, then the more knowledge the priests gained about the stars, the more they and the king would be able to control – or at least anticipate and perhaps forestall, i.e. control – events on Earth. They pursued more detailed studies of the apparent movements of stars, planets, sun and moon. Astronomy, or more particularly astrology, was an early development in all ancient civilisations.

These studies entailed mathematics. Mathematical techniques were needed to describe the patterns of movement of celestial bodies and to use them as the basis for personal and political predictions. Mathematics also proved invaluable for civil engineering projects such as pyramid-building and for calculating food rations in times of shortage.

The (usually) rich food supply of a civilised community attracted the attentions of nomadic and other pilferers from outside as well as from greedy and nefarious persons within. It must soon have become necessary to formulate laws relating to defence of the community and its food supplies. Such laws were no doubt authorised by gods. It was also necessary to construct systems of defence including city walls, strong buildings, weapons, and at least a potential army to deploy them. Law-giving and defence[3] became increasingly important facets of the work of kings.

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[2] We all have a 'natural' – a biological – tendency to seek causal connections and to generalise. If event B follows event A, even if there is no obvious connection between them, we are inclined to believe that A causes B, especially if the coincidence happens more than once. This 'default' type of thinking can sometimes give us useful knowledge, but it often misleads or generates superstitions. If you walk under a ladder and the person atop the ladder drops something on you, you are likely to infer that walking under ladders causes bad luck. As scientists, we learn to be cautions about such connections.

[3] 'Defence', of course, is a well-known euphemism. A community with sophisticated military organisation and weaponry has an irresistible urge to conquer and subjugate its less fortunately equipped neighbours. The need for defence merges very quickly into aggressive expansionist policy, and the military hero is the focus of most ancient-world epics. *Plus ça change*. It is a fact that most of the longer-lived ancient-world civilisations expanded by conquest.

Early civilisations therefore gave rise to innovations in building and military as well as agricultural technology, and to systems of law and polytheistic religions.

As the astrological and mathematical knowledge of the priests became more extensive and complicated, the system of law continued to grow, and the need to record the production and distribution of food and weapons increased, writing became necessary. All ancient civilisations produced some form of writing.

Dense, city-dwelling, non-migratory human populations invariably develop epidemic diseases. Medicine became essential to prevent population collapse and some individuals began to specialise in its practice. With the development of writing, medical treatments for various diseases were recorded for posterity.

To summarise (Fig. 2.1): early civilisations produced polytheistic religions, calendars, astronomy, astrology, mathematics, medicine, law, writing, social stratification, division of labour, civil engineering and agricultural and military technology. But there was no direct connection in our hypothetical scenario between the knowledge and beliefs of the community and its technologies. They were the provinces of different social groups. Knowledge and technology are both intimately related

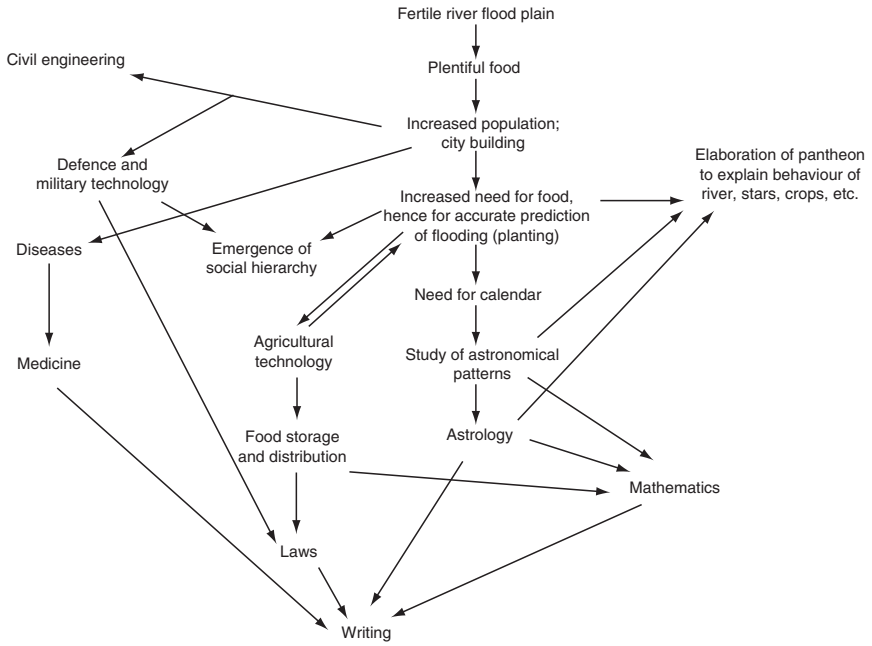

Fig. 2.1 Evolution of a hypothetical ancient civilisation. The flow diagram illustrates the scenario outlined in the text. Broadly, 'technology' and 'social organisation' are on the left of the picture and 'knowledge' is on the right. 'Medicine' was a practical art or craft and is therefore better classed as technology than as knowledge. There is relatively little interaction between the two sides of the diagram, with one important exception (not shown, since the picture is already complicated): the gods in the pantheon would be evoked to legitimise the social hierarchy and any civil engineering and military developments, as well as to maintain social cohesion