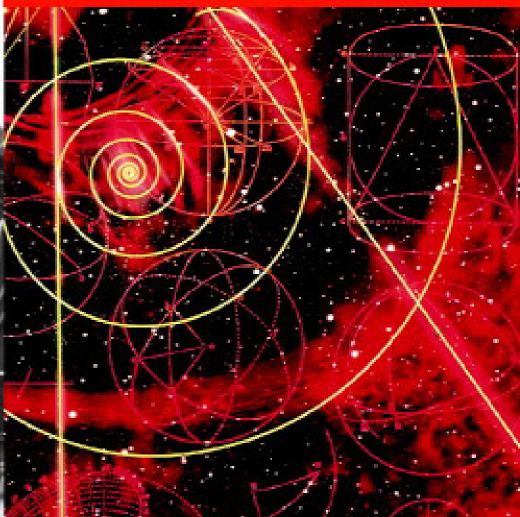
Real Science

What it is, and what it means

John Ziman



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Scientists and 'anti-scientists' alike need a more realistic image of science. The traditional mode of research, *academic* science, is not just a 'method': it is a distinctive culture, whose members win esteem and employment by making public their findings. Fierce competition for credibility is strictly regulated by established practices such as peer review. Highly specialized international communities of independent experts form spontaneously and generate the type of knowledge we call 'scientific' – systematic, theoretical, empirically tested, quantitative, and so on. Ziman shows that these familiar, 'philosophical' features of scientific knowledge are inseparable from the ordinary cognitive capabilities and peculiar social relationships of its producers. This wide-angled close-up of the natural and human sciences recognizes their unique value, whilst revealing the limits of their rationality, reliability, and universal applicability. It also shows how, for better or worse, the new 'post-academic' research culture of teamwork, accountability, etc. is changing these supposedly eternal philosophical characteristics.

John Ziman is well known internationally for his many scholarly and popular books on condensed-matter physics and on science, technology and society. He was born in 1925, and was brought up in New Zealand. He took his DPhil at Oxford and lectured at Cambridge before becoming Professor of Theoretical Physics at Bristol in 1964. His research on the electrical properties of metals earned his election to the Royal Society in 1967. After voluntary early retirement from Bristol in 1982 he devoted himself to the systematic analysis and public exposition of various aspects of the social relations of science and technology, on which he is a recognized world authority. He was for many years chairman of the Council for Science and Society, and between 1986 and 1991 he headed the Science Policy Support Group. He is currently Convenor of the Epistemology Group.

To Joan: In Heart, Mind and Spirit.

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Preface

The seeds of this book were sown forty years ago. I was always infatuated with science and beguiled by philosophy. They seemed made for each other – and for me. But the better I came to know science, the more I realized that the philosophers were not telling it like it is. Then, sometime around 1959, I was asked to review Michael Polanyi's *Personal Knowledge*[1] and Karl Popper's *The Logic of Scientific Discovery*[2]. Each of these great books says important things about science; but in both I noticed a whole pack of dogs that didn't bark. What about the web of lectures, examinations, seminars, conferences, papers, citations, referee reports, books, personal references, job interviews, appointments, prizes, etc. in which my scientific life was entangled? Surely these must have some influence on the work I was doing. So in radio talks and articles I began to say strange things, such as 'Science is *social*' and 'Research is a *profession*'[3].

Those were rash words for a young and aspiring physicist without official credentials in philosophy or sociology. Nevertheless, the heterodoxy was overlooked and my academic career prospered. The books in which I developed this theme – *Public Knowledge*[4], *Reliable Knowledge*[5] and *An Introduction to Science Studies*[6] – were also very well received, and are still read and cited. Indeed, many of the notions that germinated in these books have since been planted out more formally by other scholars. And just as I foresaw, sociology has superseded philosophy at the theoretical core of 'science studies'.

This metascientific revolution has certainly opened science to much more searching enquiry. But the spirit in which this enquiry has been conducted has actually widened the gulf between those who do science and those who observe their doings. What is more, as I pointed out in detail in *Prometheus Bound*[7] and *Of One Mind* [8], science itself is changing rapidly, as a profession and as an institution. What is happening? Where are we going? Now, more than ever, scientists, science users and science watchers need a clear vision of how it really, really works and what it can really, really do. But just when they ought to be getting sympathetic, well-informed advice from their metascientific colleagues, they are being offered little but deconstruction and doubt.

It seems to me, nevertheless, that a much more substantial model of science can be discerned within the booming buzzing confusion of contemporary science studies. So, what can I now do to bring this model out into the open, to help science understand itself? In the end, it comes down to the same basic question: is science to be *believed* – and if so, in what sense? This is a much more subtle question than it used to seem. For all their labours, the philosophers have failed to come up with any simple, generally agreed principle on which belief in science might be safely grounded. But sociological critiques are vacuous without reference to the specific contexts in which beliefs are held or made. When I said that science is *social*, I meant that this context includes the whole network of social and epistemic practices where scientific beliefs actually emerge and are sustained.

The trouble is that this network is not regulated by any single prince or principle. To appreciate the significance of scientific knowledge, one must understand the nature of science as a complex whole. That is why I decided, about five years ago, to start again from scratch and work systematically through the whole argument. As in all my writings *about* science, I wanted to show that this argument did not require much scientific knowledge as such, but could be presented perfectly clearly in the everyday language of the common reader. The line of reasoning of this book is lengthy, and visits many different academic sites, but it is not at all technical or intellectually convoluted.

But I also wanted to show that this line of reasoning is no longer a personal fancy. The naturalistic account of science that I am presenting in this book is accepted – albeit tacitly – by numerous reputable scholars. This is clear from the the size of the bibliography, even though this does not pretend to cover all the standard metascientific literature. Indeed, this book would never end if I had set out to expound and/or refute all that has been written about the nature of science, most of which is irrelevant or tangential to my main argument.

But that still left me with a practical problem. I wanted to say what I thought in my own words; so how should these be linked to the words and thoughts of so many other authors? A mosaic of verbatim quotations would have been unreadably ponderous. Even the scholarly practice of citing every author by name in the text – e.g. 'As Tadpole & Taper (1843) have shown (see also Disraeli 1844) . . . .' – would have interfered with the flow of ideas, and repelled the non-academic readers to whom this book is mainly addressed. On the other hand, the lazy custom of mentioning by name just a few of the usual suspects – Karl Popper, Thomas Kuhn, Robert Merton, Donald Campbell, and so on – does less than justice to many less eminent scholars whose ideas were no less perceptive and original in their time. Or, to put it another way, what really matters is the idea itself, not whether it is conventionally associated with some famous name.

What I have done, therefore, is to indicate all such linkages in the main text by inconspicuous superscripts referring to endnotes on each chapter. To avoid loading these notes down with formal bibliographic information, which tends to be very repetitive and difficult to scan, I have compacted this into a comprehensive alphabetical list of references, accessible directly from the notes by the author's name and date. Moreover, since each entry on this list bears a coded reference back to the various notes where it is cited, the bibliography also operates as an author index for the book as a whole.

But what else beside such bibliographic pointers should these notes contain? In principle I am permissive in such matters, and have always enjoyed reading (and even composing) the addenda, qualificanda, divertenda, detractenda, joculanda, etc. with which a gristly book can be made more palatable. In practice, however, notes easily get out of hand. As footnotes they clutter the printed page, and as endnotes they are out of context. A more austere academic tradition would restrict notes to their ostensible function of relating the contents of the cited work specifically to the place in the text where they are cited. Thus, in addition to recording intellectual priorities, they should give the reader an indication of the attitude of the cited author to the point being made, whether of enthusiastic agreement, qualified acceptance or downright opposition.

But as I have observed ruefully when my own work has been cited by others, that can seldom be done accurately or equitably in a few words. Suppose, for example, that I want to cite Kuhn (1963) on 'paradigms'. Yes, he should certainly get abundant credit for first formulating this invaluable concept – but did he mean exactly the same by it as I am now proposing? Shouldn't I at least hint at differences through verbatim quotes?

What about his later responses to the critical literature that it provoked? How have other scholars interpreted this concept – and so on? Before you know where you are, your note has become a small essay. Practise the same scrupulosity for hundreds of other equally worthy authors, and your whole book has again drowned in its own notes.

Presenting references satisfactorily is a hard problem in a non-academic book. So I have cut the Gordian knot, and included nothing in the notes beyond the formal bibliographic citation. This could refer to anything from a favourable treatise to a scornful aside. But at least it indicates a linkage, a certain congruence of interest, a wave of recognition to a fellow pilgrim on the path through the forest, an invitation to further discourse on a theme of mutual intellectual concern. Academic reviewers will never, of course, forgive this breach of ponderous current practice; but those for whom this book is really written may well be grateful for all those unwritten pages that they don't have to buy or pretend to read.

Finally, I ought to acknowledge the help of all those kind people who have contributed to the creation of this book. Ah, but they are too numerous to list individually. As I said, I began thinking and talking about these matters years ago, and have discussed them personally, pro and con, back and forth, with a great many other scholars with similar interests. In fact, this list would include about half the authors I have cited in the bibliography – although I guess that some of these would not wish to have it thought that they had actually *helped* to bring *these* ideas to birth! Let me just say 'Thank you all!', for the courtesy, conviviality, collegiality and straightforward friendship that has graced these innumerable conversations and communications.

John Ziman
Oakley, August 1998

1

A peculiar institution

1.1 Defending a legend 1

Science is under attack. People are losing confidence in its powers. Pseudo-scientific beliefs thrive. Anti-science speakers win public debates. Industrial firms misuse technology. Legislators curb experiments. Governments slash research funding. Even fellow scholars are becoming sceptical of its claims[1].

And yet, opinion surveys regularly report large majorities in its favour. Science education expands at all levels. Writers and broadcasters enrich public understanding. Exciting discoveries and useful inventions flow out of the research laboratories. Vast research instruments are built at public expense. Science has never been so popular or influential.

This is not a contradiction. Science has always been under attack. It is still a newcomer to large areas of our culture. As it extends and becomes more deeply embedded, it touches upon issues where its competence is more doubtful, and opens itself more to well-based criticism. The claims of science are often highly questionable. Strenuous debate on particular points is not a symptom of disease: it signifies mental health and moral vigour.

Blanket hostility to 'science' is another matter. Taken literally, that would make no more sense than hostility to 'law', or 'art', or even to 'life' itself. What such an attitude really indicates is that certain general features of science are thought to be objectionable in principle, or unacceptable in practice. These features are deemed to be so essential to science as such that it is rejected as a whole – typically in favour of some other supposedly holistic system.

The arguments favouring 'anti-science' attitudes may well be misinformed, misconceived and mischievous. Nevertheless, they carry surprising weight in society at large. Those of us who do not share these attitudes have a duty to combat them. But what are the grounds on which science should be defended?

Many supporters of science simply challenge the various specific objections put forward by various schools of anti-science. In doing so, however, they usually assume that the general features in dispute are, indeed, essential to science. They may agree, for example, that scientific knowledge is arcane and elitist, and then try to show that this need not be a serious disadvantage in practice[2]. The danger of this type of defence is that it accepts without question an analysis which may itself be deeply flawed. In many cases, the objectionable feature is incorrectly attributed to 'science', or is far from essential to it. Dogged defence of every feature of 'the Legend'[3] – the stereotype of science that idealizes its every aspect – is almost as damaging as the attack it is supposed to be fending off.

1.2 Science as it is and does

In the long run, science has to survive on its merits. It must be cherished for what it *is*, and what it can *do*. The moral basis for the defence of science must be a clear understanding of its nature and of its powers. One might have thought that this understanding was already widely shared, especially amongst working scientists. Unfortunately, this is not the case. Most people who have thought about this at all are aware that the notion of an all-conquering intellectual 'method' *is* just a legend. This legend has been shot full of holes, but they do not know how it can be repaired or replaced. They are full of doubt about past certainties, but full of uncertainty about what they ought now to believe.

A more up-to-date and convincing 'theory of science'[4] is required for a variety of other reasons. The place of science in society is not just a matter of personal preference or cultural tradition: it is a line item in the national budget. There are increasing tensions in the relationships between scientific and other forms of knowledge and action, such as technology, medicine, law and politics. Scientists are asked by their students whether they are being prepared for a vocation or for a profession. People are expected to make rational decisions arising from, and affecting, radical changes in the way in which science is organized and performed.

The uncertainties and confusions have not been dispelled by the sociologists who have displaced the philosophers from the centre of 'science studies'. On the contrary, the various schools of sociological 'relativism' and 'constructivism' that have emerged in the past twenty years[5] often seem to be hostile to science, and eager to belittle its capabilities. In their enthusiasm to expose scientific pretensions to objectivity and truth, they exaggerate the genuine uncertainties and perplexities of scientific research[6], and propagate an equally false and damaging stereotype of pervasive cynicism and doubt. Despite repeated assertions that they too love science, and don't really dispute its practical claims, they thus confirm the natural scientists in their mistrust of the social sciences, and often seem to ally themselves with anti-scientific populism.

It must be emphasized, however, that this sceptical stance does not go unchallenged in the world of science studies. Many *metascientists* – that is, philosophers, sociologists, political scientists, economists, anthropologists and other scholars who study science as a human activity – have pointed out the weaknesses of this stance. They try to understand just what scientists think they are doing when they engage in research, and how much weight should be given to their results. They are interested in the way that scientists work, as individuals and as groups, and how this affects their findings. They may not accept scientific knowledge as uniquely true and real, but they do treat it as a peculiar human product worthy of special study.

These expeditions into the unknown heart of science branch out in all directions[7]. Metascientists make their observations through the intellectual instruments of many different disciplines, and analyse what they see along many different dimensions. The study of each such aspect has become a research specialty in its own right, with results that are often scarcely intelligible outside that specialty. We know much more about science nowadays than can be put together into a comprehensive, coherent image.

Metascientific pluralism is a wise recoil from overambitious attempts to encompass a complex human enterprise in a single formula. Nevertheless, these various modern accounts of science are not all disconnected. They start from the outside to explore the same range of ideas, activities and institutions, and they often come back with similar findings. In each case – that is the way that scholars work – they tend to put a personal interpretative spin on these findings. But one often discovers that essentially the same tale is being told by travellers who set out with quite different intellectual goals[8].

These findings are consistent with a relatively straightforward, if sketchy, overall picture of what science is and does. In effect, a sociological dimension is introduced, not to replace the traditional philosophical dimension but to enlarge it. Ideas are seen as *cultural* elements as well as *cognitive* entities. *Individual* acts of observation and explanation are seen to gain their scientific meaning from *collective* processes of communication and public criticism[9]. The notion of a scientific 'method' is thus seen to extend outside the laboratory to a whole range of social practices. And so on.

This new picture of science is somewhat more complicated than the outmoded stereotype. It is not so sharply defined. It does not claim total competence. It treats human knowledge as a product of the natural world. It does not pretend to be impregnable against thorough-going scepticism or cynicism. It calls for more modesty and tolerance than scientists have customarily cultivated about themselves and their calling. But it does provide a stout intellectual and moral defence for science at the level of ordinary human affairs – the level at which nothing is absolute or eternal, but where we often forget that life is short, and feel passionately about pasts that we have not personally experienced, or plan conscientiously for the future welfare of people whom we shall never know.

1.3 A peculiar social institution

The most tangible aspect of science is that it is a *social institution*. It involves large numbers of specific people regularly performing specific actions which are consciously coordinated into larger schemes. Although research scientists often have a great deal of freedom in what they do and how they do it, their individual thoughts and actions only have *scientific* meaning in these larger schemes. Like many facts of life, this is so obvious that it was for long overlooked!

Science is one of a number of somewhat similar institutions, such as organized religion, law, the humanities and the fine arts. These institutions differ from one another in interesting ways. But what they all do – among many other things – is to produce quantities of *knowledge*. The peculiarity of science is that knowledge as such is deemed to be its principal product and purpose. This not only shapes its internal structure and its place in society. It also strongly colours the type of knowledge that it actually produces.

The sociological dimension is thus fundamental to our picture. But the self-styled 'sociologists of scientific knowledge'[10] have become attached to a principle of 'symmetry' as between different forms of knowledge, and are mainly attracted to the features that science shares with other forms of social life. They have therefore largely ignored the procedures, practices, social roles, etc. that actually distinguish science from other institutions. Attention to these distinctive features does not mean that science is sacred. Scientific life would not be human if it were not permeated with folly, incompetence, self-interest, moral myopia, bureaucracy, anarchy and so on. It is no longer news that even the most high-minded institutions are depressingly alike in some of their less admirable characteristics. But it is only when we have understood the *differences* that make scientific knowledge unusual that we can appreciate the *similarities* that make it ordinary.

This may seem a rather obvious point, but it needs firm emphasis[11]. Sociologists who deliberately 'bracket out' the distinctive institutional characteristics of science inevitably arrive at an extreme version of cultural relativism [*8.13*, *10.4*]. This, in turn, generates a sceptical quagmire that blocks every path towards revision of the traditional Legend. They really have no reason to deny the plain evidence of our senses that science *does* have a number of unmistakable social features which should surely figure in our picture of it.

1.4 A body of knowledge

Science generates *knowledge*. The actual observations, data, concepts, diagrams, theories, etc., etc. that make up this knowledge often appear in tangible forms, as written texts, maps, computer files and so on. Some of it is also very well founded, and no more questionable in practice than the warmth of the sun or the solidity of the ground under one's feet. But there are many forms of knowledge[12], so what makes any particular form of it *scientific*? And if it *is* scientific, how firmly should we *believe* in it?

Until recently, the answers to such questions were considered entirely a matter for philosophy. Scientific knowledge was thought to be no more than a carefully edited version of aggregated reports of innumerable independent explorations of the natural world. What made these explorations 'scientific' was their particular subject matter, and the particular way in which they were carried out. The main project of philosophers of science was to define the general principles of *demarcation* between scientific and non-scientific knowledge[13]. They could then show – it was hoped – that knowledge fully satisfying these principles was – or would be – worthy of complete belief. In the heyday of the Legend it was even argued that the idea of 'non-scientific knowledge' was a contradiction in terms, as if there were no other reality than the world revealed by science.

The failure of this project[14] has not taken these questions off the metascientific agenda. Our picture of science is still heavily impregnated with *epistemology* – that is, the 'theory' of knowledge. What is now clear is that fundamental epistemological issues cannot be resolved by an appeal to abstract general principles. For example, as we have already noted, scientific activity involves *social* factors operating far outside the normal scope of philosophy[15].

Metascientists are also beginning to realize that it is not feasible to separate 'knowledge' from acts of 'knowing'. Scientific knowledge is not just a disembodied stream of data or the books on a library shelf. It is generated and received, regenerated or revised, communicated and interpreted, by human *minds*. Human mental capabilities are remarkable, but also limited. They are also closely adapted to the *cultures* in which they operate. Many of the characteristic features of science are shaped by the psychological machinery that scientists employ, individually and collectively, in their study of the world. In other words, *cognition* is the vital link between the social and epistemic dimensions of science.

The appearance of cognitive factors in our picture is a decisive break with the Legend. Philosophers of science have always steered clear of 'psychologism', for fear that it would rob science of its much-prized objectivity. Personal judgements of fact or meaning might well be required to make discoveries, but they were bound to introduce irrational elements which would have to be systematically excluded from the final analysis.

Fortunately, modern cognitive science is not completely clouded over with subjectivity. Human minds are all different, but they are built to the same general plan, and acquire common standards from the scientific culture of their research discipline. For many purposes they are just as alike as many artificial instruments of perception, calculation and communication. In practice, the *social stability* of scientific knowledge is a reasonable indicator of its objectivity.

1.5 Naturalism in the study of Nature

Our new picture of science thus draws on a very wide range of academic disciplines. Conventional philosophical questions about what is to be believed have to be combined with the sociological analysis of communities of believers. Perception, cognition and language all play their part. Even the humanistic concept of *empathy* – the capacity to enter into the thoughts and feelings of another person – has its place in the social and behavioural sciences [*5.11*]. A philosophy *of* science does not have to encompass all that might be required of a general philosophy *for* science[16], but it still involves many elements drawn from wider accounts of the human condition.

The involvement of so many disciplines does not merely complicate the picture. It also means that we are taking a *naturalistic* point of view[17]. By including 'scientific' concepts in our overall picture of science itself, we are assuming that it too is 'natural', in the sense of being susceptible to description and explanation by the same methods, and according to the same criteria, as other features of the natural world – including human society.

To be consistent with other forms of knowledge, epistemological naturalism has to be *evolutionary*[18]. Modern science is seen as the heir to an unbroken lineage of knowledge-acquiring organic forms, stretching back to the beginnings of life on earth [*9.7, 10.3*]. This is a useful unifying principle for what sometimes seems no more than 'a cluster of symbols, languages, orientations, institutions and practices, ways of seeing etc.'[19]. It recognizes that many of the peculiarities of science are historical survivals rather than current necessities, and accepts that the institution as a whole is bound to change over time.

Epistemological naturalism also emphasizes the *dynamism* of science. Even the knowledge it generates is continually changing. The noun 'science' is closely identified with the verb 'to research', indicating that it is an active *process*. At any given moment, this process involves the coordinated actions of many quasi-permanent entities, such as research scientists, research instruments, research institutions, research journals etc. By its very nature, science is a complex *system*[20]. It cannot be understood without an explanation of the way that its various elements *interact*.

A naturalistic 'picture' of a dynamic system is a *model* [*6.10*]. Although this word means no more than a simplified representation of a complex entity, and is often used very loosely to mean any abstract theory, it conveys intuitive notions of internal structures and mechanisms. In ordinary scientific usage, a theoretical model can be taken apart conceptually, and then put together again to make a working whole. Meaningful theoretical questions can then be asked about the functioning of the various parts, and the consequences of specific changes in their make up or interactions.

Such questions are not just theoretical; they arise continually out of practical issues in the real world – issues that are often in dispute between the defenders of science and its opponents. Has our understanding of nature been influenced by the gender-specific cognitive capabilities of predominantly male researchers? Does peer review quench scientific creativity? What scientific weight should be attached to a single, carefully recorded, but unconfirmed observation? To deal with questions of this kind we need more than a new 'theory' or 'picture'. This book is about the new *model* of science that is required to replace the stereotype of the Legend.

1.6 Keeping it simple

Naturalism, as such, is not enough to hold our model together. It merely affirms that scientific research is not essentially distinct from the many other ways in which we humans typically get to know about 'life, the universe, and everything'. In principle, we should be taking a holistic view that covers 'the whole picture'. In practice, each discipline may still look at only one particular aspect of this picture, and report what it sees in its own particular language.

The fact is, quite simply, that the barriers of comprehension between these languages are so high that a *transdisciplinary* viewpoint is required to transcend them. It is all too easy to be mentally trapped in a particular discipline, unable to cross the conceptual Divide into other modes of thought. This is a familiar situation in the natural sciences. What, for example, is a 'gene'? Is it a heritable trait, as seen by the geneticist? Is it a segment of DNA, as seen by the molecular biologist? Is it a protein factory, as seen by the biochemist? Is it a developmental switch, as seen by the embryologist? Is it even, perhaps, an active, utterly selfish being, as depicted by some evolutionists? It takes the general standpoint of the biologist to see these diverse concepts as different aspects of the same entity.

Similarly, if we were to begin our metascientific explorations deep in the realm of sociology, and insist, for example, that science has to be thought of primarily as a *heterogeneous actor network*[21], we would find it very difficult to accept that it is also, in some ways, a *sequence of refutable conjectures*[22], or a *bundle of research traditions*[23], or a *problem-solving, computational algorithm*[24]. Corresponding difficulties would arise if we were start from inside any other well-established discipline. Yet valuable insights have come from each of these specialized points of view. The trouble is that, although the academic languages in which they are expressed are not necessarily 'incommensurable'[25], they have evolved independently to answer very different types of question. A great deal of intellectual boundary work is needed to translate ideas directly from one such specialized language to another and to make them consistent and coherent.

It is much more profitable to *start* looking at science from a standpoint where it can be seen and depicted – however indistinctly – as a whole. The great merit of naturalism is that it automatically takes just such a standpoint. Educated citizens of economically advanced countries know that there is 'a thing called science'[26], and can say quite a lot about it. In response to detailed questioning, they might say that it is 'a body of knowledge', or 'an organised social activity', or 'a way of life for certain people', or 'a heavy burden on the taxpayer', or 'a power for good and/or evil'. Although these answers would be very diverse, and often contradictory, they would all be based upon a shared understanding of a simple truth – that these are indeed only different aspects of a *single entity*, of whose existence they are as sure as of death and taxes.

This 'natural ontological attitude'[27] is largely tacit. Its power resides in everyday usage. It implies, and is implied by, the way in which we ordinarily talk. A familiar word such as 'scientist', 'experiment', 'research', 'apparatus', 'scientific paper', etc. can carry a whole raft of formal meanings. It may well be defined quite differently in different contexts. But in each context it is understood to refer to the same discernible element, or feature of the world. Such words thus act as mental bridges re-uniting the various aspects or dimensions into which a natural entity may have been analysed. In saying, for example, that 'science involves experiments', we are not really bothered by the fact that the philosopher's concept of an experiment as, say, 'an attempt to refute a hypothesis', seems quite remote from the economist's characterization of it as 'a speculative investment whose ultimate rent may be difficult to appropriate'. We simply rely on our practical knowledge that these are just two different ways of looking closely at the same type of activity.

Many scholars abhor the fuzziness and ambiguity of the 'natural language' used by 'lay persons'. Their ideal would seem to be a precise, unambiguous, quite general *metascientific language* into which all the results obtained by different disciplines could be accurately translated, without fear or favour. But this is an unattainable goal [6.6], even for the representation of a much less complex entity than modern science.

Failing that, they prefer to concentrate on enlarging and perfecting their own particular domain, perhaps hoping that its specialized viewpoint could eventually be widened to take in the whole scene.

This is a perfectly reasonable preference. In science studies, as in other scholarly enterprises, progress is made largely by narrowly focussed research [*8.3*]. I am not in any way suggesting that this research is invalid or inappropriate. Nor am I insisting that its results are irrelevant unless they can be expressed in non-specialist terms. The true strength of a discipline often resides in a highly specialized framework of concepts [*8.4*] which can only be mastered by a lengthy effort.

But the purpose of this book is not to review in detail the work of scholars in these various specialties: it is to derive from their work a model of science that can be understood and accepted by a much wider public. This model has to be presented in terms that are equally widely shared. To start with, these terms must already be 'common knowledge' – that is, they cannot be much more sophisticated than the words and concepts that people ordinarily use when talking about science.

At first sight, this would seem to make everything unacceptably vague. Take, for example, the very word 'knowledge'. What does it mean to say that we 'know' something? Does it convey broadly that we are 'familiar with it', or 'have been informed of it', or does it imply well-founded conviction, if not complete and justifiable certainty? As any good dictionary will show, ordinary English usage covers a whole range of meanings, often in closed circles of reciprocal definition. But what would be gained here by trying to define 'knowledge' more precisely? Not only would it pre-empt the whole issue of scientific credibility; it would also rob us of a general word for a familiar human capability.

The incorporation of bodily experiences into mental traces is a primary feature of our very existence. By referring to it in ordinary lay terms we show that we understand that 'knowing' is a 'fact of life', and as such is a major functional module in our model of science. As a natural process it certainly demand systematic analysis. But the main argument would not be made more definite if we took this module apart and reduced it formally to more basic elements which were less familiar but really just as vague [*10.8*]. Admittedly, it doesn't have an adjectival form; but in using the philosopher's word 'epistemic' I simply mean 'relating to knowledge' in the same everyday sense.

Let me emphasize, however, that the new model is not already latent in 'folk discourse', just waiting to be developed like a photographic image. It is not even widely accepted in the world of science studies, although I believe that it is now beginning to take shape in the minds of certain other scholars there. To put this model together I have had to enter quite deeply into various specialized disciplines, select what seemed to be relevant conceptual material, translate this material roughly into lay terms, and trim the various bits and pieces into an untidy fit.

No earnest scholar in any of these disciplines will be satisfied by such a patchwork of heterogeneous concepts. I must surely have missed out, misunderstood, or misrepresented innumerable points that are deemed to be crucial in each particular domain. But this book does not have to be 'academically correct'. It is addressed to a more general audience, including a great many people who have had first-hand experience of scientific life and work. They will reject elaborate or esoteric interpretations of scientific activity that seem remote from this experience. Their acceptance is the real test both of the adequacy of the model and of the intelligibility of my account of it[28].

To sum up: I could not say what I wanted to say in this book *except* in the most direct and simple 'lay language'. This is not just because most people would not otherwise be able to understand it, nor because scientists would not otherwise recognize themselves in it. It is also because this is the only language in which 'science' stands for a many-sided natural entity, and in which there is a consistent terminology for describing all its aspects.

2

Basically, it's purely academic

2.1 Framing the indefinable

We encounter science as a *natural kind*[1], not as an abstract *category*. In other words, like a chair, or a tiger, or a city, we recognize it when we come across it, without having to refer to an explicit formula. Indeed, such a formula is not feasible. It would not only have to be elaborate enough to indicate that science has many different aspects – institutional, mental, material, and so on. It would also have to be broad enough to extend over many different instances of scientific activity, from classifying beetles to theorizing about black holes, from recording folk tales to mapping the human genome, from ancient Chinese medicine to modern Japanese pharmacology, from explaining earthquakes to failing to explain inflation.

A catalogue of all these aspects and instances would obviously be quite unmanageable. It would merely demonstrate that science is too diverse, too protean, to be captured in full by a *definition*. Moreover, any such definition would pre-empt the outcome of our enquiry. By telling us in advance what science *is*, it would effectively determine what we would later surely find. We may be very well informed about science, and have a very good idea of various features that are typical of it, but we must be careful not to insist that any of these features are invariable or definitive.

How can we make a model of something so indefinable? The first thing to do is to *frame* it[2]. In effect, we must enclose it in notional boundaries, and limit the analysis to a carefully chosen *exemplar* or *ideal type*. A model based on a detailed study of this exemplar may not depict correctly all the various instances of the entity under consideration, but because it represents an *actual* instance it can be made to 'work' in a self-consistent manner. This, after all, is just how natural historians have always dealt with the variability of individual organisms, even when they belong to a single species.

2.2 Narrowing the frame

The scope of 'science' is immense. In the time dimension, it includes instances stretching far back into history, or even prehistory. We may well suppose that the development of agriculture was facilitated by 'scientific' observations of the germination of seeds, and or that the legends governing metallurgical practices were akin to 'scientific' theories. Modern science evolved from the ideas and techniques of the great literate civilizations of Eurasia, whose achievements still amaze us.

But the intellectual and social distance between ancient Athens and modern Cambridge is too great to be bridged by a single model. This applies even to the seventeenth century 'natural philosophers', who invented so many of our present-day scientific usages[3]. Case studies drawn from such periods are instructive mainly by comparison with more recent models. The history of science inspires many valuable metascientific insights but our exemplar must be drawn from a narrower, more recent frame.

'Science' also extends far into everyday life. The farmer adding growth hormones to pigfeed is, in a sense, 'being scientific'. So is the police officer collecting blood samples, the sailor heeding a weather forecast, the rich man downsizing his firm in the name of supply-side economics, and the poor Third World woman half-starving her baby on artificial milk. But everybody would agree that there is much more to science than the use of very sophisticated techniques or hyper-rational argument[4] in daily life.

In common parlance, the word 'science' often includes medicine, engineering and other practical technologies. This is what is usually meant, for example, in statements deploring the deficiencies of 'public understanding of science'[5]. These activities are certainly closely associated with science, and permeated with scientific knowledge. Even in routine practice, they often use the same elaborate instruments, and rely upon the same sophisticated theories. Indeed, it is a notable feature of the past few decades that many of the boundaries between the natural sciences and their associated technologies have been dissolving before our eyes[6].

Yet medical and engineering practitioners firmly insist that they are professionally and intellectually distinct from scientists[7]. In other words, their model of a science differs in some fundamental way from their model of a technology. This is obviously a very important point of principle, with many practical consequences. It is essential, therefore, that we should not prejudge this issue by including any unmistakable technologies in the frame enclosing our exemplar of science. Although the notion of a monolithic, over-arching *technoscience* [*2.8, 3.11*] is politically potent[8], it is too coarse-grained for our present study.

2.3 Research as inquiry

Technology is science in *application*: science in action is *research*. This marks out a frame in the dimension of practice. We can zoom in on our exemplar through successive layers of terms such as 'investigation', 'exploration', 'analysis' and 'explanation'. The history of science can be presented as progressively detailed and systematic *inquiry*, normally directed towards increasingly sophisticated and powerful means for *solving problems* [*4.4–4.11, 7.9, 8.1, 8.7, 10.3*].

It is popularly supposed that science can be distinguished from other modes of systematic inquiry by a distinctive *method*. This is not what is observed. The *techniques* used in scientific research are extraordinarily diverse, from counting sheep and watching birds to detecting quasars and creating quarks. The epistemic *methodologies* of research are equally varied, from mental introspection to electronic computation, from quantitative measurement to speculative inference.

These diverse methods do not fall into an obvious pattern. The significance of such features as they share can be determined only by reference to a more general model. To fix on any one of them as exemplary would once again prejudge the issue. For this reason, the frame should not exclude, on principle, any of the many techniques and methodologies that scientists actually use. In practice, that means that our model will have to be capable of exhibiting the whole range of what counts nowadays as 'good science'.

Good science produces knowledge. But research is not just *discovery* [*8.9*]. It is conscious *action* to acquire a particular kind of knowledge for some particular purpose. Even in its most exploratory mode, scientific research is always carried out according to a conscious plan[9]. This plan may be very flexible. It may only last for a week, or a day, or half an hour. Or it may require a billion dollar instrument taking years to design, build and operate. Scientists, loving research, romanticize it as a form of play. In reality, science makes little progress by inspired improvisation or artistic doodling.

What, then, is the purpose of research? The notion that it can be defined simply as 'solving problems'[10] is enshrined in the funding of research in terms of *projects* [*8.2*][11]. Researchers are expected to present detailed proposals for particular investigations. To promise a specific *outcome* would be self-contradictory. But a project proposal would seem pointless without an indication of the question or questions that might be answered by what might be discovered. Hence, the presumed purpose of research is to solve problems that can be formulated in advance.

Indeed, the societal function of science has always been thought of primarily in terms of the practical human needs that it might serve[12]. The contributions of science to the health, wealth and welfare – and war-making capacity – of mankind are legendary. Nowadays, this function is operationalized. Projects are typical instruments of *science policy*[13]. They are handles by which governments, industrial firms, medical charities and other institutions endeavour to catch hold of science and bend it to their ends.

2.4 Science in the instrumental mode

The *instrumental* attitude to science [*7.2*] is summed up by the acronym 'R&D' – a hybrid of scientific *Research* and technological *Development*. This locates science at the 'upstream' end of a one-way process by which useful discoveries and inventions eventually flow down into the home, the shop, the hospital and the workplace. The *linear model of technological innovation* is obviously over-simplified, and calls for considerable elaboration and modification[14], but it underlies what most politicians, business people, civil servants and journalists say about science.

Socio-economic theory sanctifies science as a wealth-creating component of R&D or demonizes it as an active principle in the techno-scientific 'military-industrial complex'[15]. In either case, the supposed role of research is to produce, by any feasible means, whatever knowledge is required, or seems likely to be required, to satisfy an actual, or envisaged, material need. In effect, each field of science is treated as an optional facility bolted on to the front end of a practical technology to improve its inventive power.

Industrial R&D and other forms of *applied science* do indeed constitute the greater part of all modern scientific activity [*4.10*]. Some estimates of the proportion run as high as ninety per cent[16], but this is a notional figure. There is no generally agreed definition for scientific research as a line item in the financial accounts of government departments and commercial firms. In the laboratory, factory, hospital or field station, science is inseparably intermingled with technological development, design, demonstration and practice.

The *instrumental mode* dominates all other forms of science in its use of human and material resources, and in its direct impact on society. It governs the conception that many well-informed and influential people actually have of science. Surely this is the ideal type that our model should represent.

The trouble is that such a model would be very schematic and banal. In its details, it would be pulled apart by the instrumental demands of the diverse interests it has to serve [*7.6*]. Institutionally, for example, an R&D organization has to conform to the managerial practices of its 'owners', whether these are commercial or governmental, civil or military, private or public, entrepreneurially independent or corporately bureaucratic. The sociology of science is thus limited to the particularities of *R&D management*, with its concerns about project planning, budgeting efficiency, career ladders, administrative responsibilities, market information and so forth. These are, of course, important issues in management studies, but they are not peculiar to scientific work.

Again, from a philosophical point of view, issues of validity, reliability, objectivity and so on are reduced to a single question: 'Does it work?' But this *pragmatism* [*7.2*] has to be applied under very varied circumstances, and is not founded on a coherent set of general principles. What would the answers to this question have in common, as between, say, a novel surgical procedure and a new type of microchip, an experimental fusion facility and a genetic test for schizophrenia, an economic indicator and a remote-sensing satellite? In each case, there might well be a good answer, but it would be based on a particular body of scientific, technological and societal knowledge, much of which would be very debatable.

Much wise thinking has been devoted to such cases. But this wisdom is not coherent or self-contained, for it almost always involves personal, political and cultural *values*. For this reason, the metascientific spotlight has shifted to *ethical* issues[17]. The interests and motives of the 'owners' and sponsors of R&D are questioned. The formulation of 'needs' is scrutinized. The sensitivity of scientists to moral dilemmas is queried. Such issues are so diverse and disputable that science figures in them mainly as a 'black box'. It is treated as a powerful but mysterious machine whose use has to be carefully watched, and brought under social control. But the way in which this machine works is of little interest, provided that what it produces is morally acceptable to society.

This concentration on ethical issues is, of course, appropriate and desirable [*7.3–7.10*]. Social antipathy to science normally arises out of perceived threats to treasured values, and should be accepted or contested as such. But more general questions of validity also enter into such debates. Are established scientific theories perfectly reliable? What weight should be given to a highly unorthodox scientific opinion? Can the uncertainties of scientific prediction be quantified? Does 'more research' always produce better understanding? Could all that we ever needed to know be deduced from a single principle? Questions such as these are often at the centre of apparently practical disputes, and cannot be answered without an appeal to our deeper beliefs about the nature of science and of scientific knowledge.

What happens, unfortunately, is that one side falls back on the Legend – the romantic philosophical conception of science as a 'method' of guaranteed, unassailable competence[18]. The other side then claims support from populist sociological works that caricature and debunk normal scientific activity[19]. The result is a stalemate. The champions of each side talk past each other, as if in different worlds. In other words, a purely instrumental model of science is an empty shell. Its intellectual vigour, like its spiritual health, does not have sources within itself, and has to be sustained from elsewhere.

2.5 Basic research as a policy category

Scientific research is not, in fact, entirely instrumental. At least 10% of scientific activity is what is often called 'pure science' – or even just 'science' – to mark it off from applied science, technological development and other high-tech work. At first sight, this seems to solve our problem. 'Pure' science, surely, is the ideal type. Here, almost by definition, is the natural frame we have been seeking. Analysis of exemplars chosen from within this frame should provide a naturalistic model of science free of alien elements.

Unfortunately, this is a circular argument. It proposes no independent criterion of purity. Thus, anyone who *claimed* to be a 'pure scientist' would apparently be qualified to judge what should count as 'pure science'. To escape tautology, we need to be able to define our frame by some other means than the say-so of those who may have an interest in being inside or outside it. Further analysis of the whole concept is necessary.

Other terms, such as 'open-ended', 'curiosity-driven', 'blue skies', 'basic', 'foundational' or 'fundamental', are widely used to make essentially the same distinction. Celebratory rhetoric falls back on stock phrases, such as 'honest seekers after truth', who are 'pushing back the frontiers of knowledge', etc. These terms are not synonymous, and are used under somewhat different circumstances to emphasize somewhat different aspects of non-instrumental scientific activity. Between them, however, they indicate features around which a frame might be constructed.

For example, official documents customarily refer to one of the components of R&D as *basic research*. This usage, along with the associated notion of *science policy*, did not become common until the 1970s. But what does it mean? The standard 'Frascati' definition[20] is peculiarly negative:

> 'Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, *without any particular application in view*'.

Various attempts to elaborate on this definition all retain a version of the clause I have italicized. In more Basic English: 'Basic research is what you are doing when you don't know what you are doing it for!'

The desire to distance basic research from all instrumental purposes is understandable. But even if such a residual category is logically acceptable, it is very fuzzy. What, for example, are the practical applications that 'might be in view'? Are they restricted to the 'objectives' stated in a formal project proposal – 'The purpose of this research is to discover a more alluring cheese for baiting a bigger and better mousetrap . . .' and so on? Or might they be inferred from the nature of the problem which the research is designed to solve: – 'The problem of why cheese attracts mice to mousetraps has long puzzled rodentologists . . .' etc.? Should one discount a completely unrealistic objective, such as using quarks as a source of electrical power[21]?

The trouble with formal research objectives [*8.2*] is that nobody expects them to be met to the letter. They are addressed to particular interests. If you are approaching The Kindly Killer Kompany (KKK) for a contract, indicate that a patent is in the offing. For the Small Animal Protection Society (SAPS) you suggest that the research could lead to the development of an anti-mousetrap olfactory vaccine. The Fundamental Biology Research Council (FBRC) would expect you to show just how deeply the same project might be expected to advance our understanding of zoo-physio-micro-molecular-ethological phenomena. And so on.

The Russian dolls of patronage in modern science confound the issue. OK, so Dr X, an enthusiastic zoo-physio-micro-molecular-ethologist, has conceived this exciting FBRC project as a personal contribution to *basic* knowledge in his subdiscipline. But he is working under Professor Y, who heads an interdisciplinary group specifically devoted to *oriented basic* research on the behaviour of rodents in man-made environments. This group is partly financed by SAPS, whose Chairman, Lord Z, thinks of it as *applied* research, along the way to the development of a novel generic technology. Little do they know that most of the funding of the SAPS comes by a roundabout route from the KKK, who have already gone beyond the stage of *pre-market* research on the design of an even kindlier mousetrap based on just such a principle. How many of these boxes should we open, or close, in our hunt for a label?

In the end, the notion of pure science cannot be defined in policy terms. Policy [8.7] is all about future action. Policy talk is so steeped in practical intentionality that it cannot attach any precise meaning to a non-instrumental activity. Policymakers try to define basic research by exclusion, and then have to invent elastic concepts such as 'potential applicability' to bridge the gap that they have created[22].

Indeed, even the classification of activities on the applied side of this gap is thoroughly confused[23]. The term 'strategic research'[24], for example, is often used to justify rather general research that might later turn out to be of service in reaching certain specific practical goals. But it is seldom difficult to imagine an *eventual* application for almost any competent research in almost any field of biology, chemistry or the life sciences[25]. Interpreted in that spirit, the Frascati formula would limit basic research to remote disciplines such as pure mathematics, high energy physics and cosmology. Nobody supposes that 'pure' science ought to be framed so very narrowly.

2.6 Fundamental knowledge as an epistemic category

Pure science is often said to be concerned mainly with *fundamental* problems. The Frascati formula describes *basic* research as being undertaken 'primarily to acquire new knowledge of the *underlying foundation* of phenomena and observable facts'. Metaphorically speaking, scientific knowledge is likened to a many-storeyed building. It is supposed that the products of research can be arranged in a layered structure, where the 'deeper' layers provide support for the layers that are 'above' them.

This gravitational metaphor[26] expresses a familiar feature of scientific progress. Certain bodies of knowledge have been found to stand in a one-way relationship to other bodies of knowledge, which it is said they can *explain* or to which they can be *reduced*. This finding has been elevated into a general epistemic principle. A widespread belief in *reductionism* is typical of modern science.

The grounds for this belief will be explored in a later chapter [*10.8*]. We must be careful, therefore, not to prejudice the results of this exploration by tacitly taking them for granted. Indeed, if we were to do so, we would almost inevitably be drawn to the same implausible conclusion as in the previous section. If reductionism really rules, then the purest, most exemplary, forms of science would again seem to be elementary particle physics, cosmology and pure mathematics, since these are generally supposed to be the most 'fundamental' in this sense.

In reality, science is nowhere near any such grand reductionist goal. Nevertheless, fundamentalism is regarded as a desirable feature of research. General *theories* are favoured because they seem more fundamental than specific *facts*. *Invisible* entities, such as quarks, molecules and genes, are thought to be particularly fundamental because they operate behind the scenes[27]. Research focussing on *naturally occurring* objects, such as stars, rocks and organisms, which might reveal such hidden mechanisms, is considered to be more fundamental than the study of *artificial* systems, such as magnetically confined plasmas, anti-sense DNA or insurance companies, whose existence can be explained in terms of human agency.

More generally, scientists often describe a piece of research as fundamental when it is particularly esteemed, either for greatly improving human understanding of puzzling phenomena, or for opening the way into a totally unexplored field. They thus rate it as one of the highest *epistemic* qualities of good science. It is for their fundamental contributions to knowledge that great scientists are most admired. But this is a very exclusive criterion that only applies to a very small proportion of basic research. An *exemplar*, or *ideal* type, should not be confused with an *exemplary*, or *idolized* type. When people refer to scientists 'such as Einstein (or Darwin, or Pasteur)' they are not really saying much about scientists in general. One of the defects of the traditional Legend is that its model of science seems designed solely for the personal use of rare geniuses. It would completely sabotage our project to suppose that the practice of pure science is confined to this elite group.

More seriously, as philosophers now largely agree[28], 'being fundamental' is not an objective property of scientific activity [8.5]. Basic research cannot be recognized simply by inspection of its scientific objectives or results. At best, we can say that a piece of research is more or less fundamental *in relation to some other research*. Typically, this occurs when the behaviour of a complex entity can be explained reasonably well in terms of the properties of its components [*10.1*]. But these components may themselves have simpler elements. Thus, living cells are fundamental in relation to organisms, chemical molecules are fundamental in relation to cells, atoms are fundamental in relation to molecules – and so on. But neither cells nor molecules are absolutely fundamental in themselves.

We are thus dealing with a *relative* characteristic that depends entirely on the context. Biochemistry, for example, is fundamental in a biological context, but not as a branch of chemistry. In appropriate circumstances, almost any research project might turn out to be 'fundamental' relative to *some* body of knowledge. For example, apparently routine investigations of the metabolism of micro-organisms are now turning out to be fundamental to our understanding of climate change.

This context-dependence explains why the term 'basic' is used in policy language as the antithesis of 'applied'. Policymakers are primarily interested in R&D that is clearly directed towards practical applications. In a specific organizational context, the dominant mode of research is likely to be empirical rather than theoretical, in order to make contact with everyday realities. Research that explores the foundations of this activity will thus be linked only indirectly to its applications. In effect, the Frascati formula advises policymakers to treat this type of research as non-instrumental, despite its obvious strategic potential[29]. This a sound maxim in each context, but does not solve our general problem.

The notion that some forms of research are pure because they are *intrinsically* more fundamental than others is not merely elitist. It simply does not define a fixed frame. The traditional hierarchy of the sciences put the social sciences and humanities at the top, reducing them down through psychology and biology to chemistry, physics and mathematics. But now we know that mathematics cannot be reduced to logic without reference to human languages and other social institutions. The foundations of the whole edifice are not merely insecure: they are all up in the air.

2.7 Out of pure curiosity

Pure science usually appears in government R&D statistics as a residual category with a vague label such as *advancement of knowledge*. Research managers sometimes give a positive spin to its lack of practical purpose by referring to it as *open-ended*. Sociologists and economists point to – but seldom attempt to calculate – the *cultural* value of the 'useless' knowledge obtained by pure research[30]. In the past, scientists would have said that this was work for the glory of God and the benefit of mankind[31]. This is described nowadays as *blue-skies research*, which is short for 'the pursuit of knowledge for its own sake, wherever it may lead them, perhaps up in the air, out of touch with the solid earth of established theories, etc.' The inconsistency of this image with other equally apt metaphors, such as 'exploring foundations' and 'pushing back frontiers', shows just how difficult it is to define pure science in general terms.

The idea that it is *curiosity-driven* does provide pure research with a purpose that is unrelated to any particular application. It also frames it in a new dimension. We often talk about science being powered by 'human curiosity' as if this were a collective social force[32], but we are well aware that it is essentially a variable *psychological* trait of individuals. In effect, this idea suggests that the purity of scientific research is determined by neither its purpose nor its product, but by the *personality* of the researcher. It draws attention to the researcher as a *person*, rather than as a cog in a social machine.

Curiosity is, indeed, one the most notable qualities of many (but not all) outstanding scientists. Take Einstein, again, or Darwin, or Pasteur, or Marie Curie, or Dorothy Hodgkin, or . . . It can be said of almost any seriously famous scientist that he or she had an inquiring mind, and was alert to, and fascinated by, strange ideas or events. This is almost a truism. Since research is a mode of inquiry, then a strongly motivated and effective researcher is necessarily 'inquisitive'.

Once again, we are in danger of taking just one component of scientific excellence as a framing principle. Very few of the thousands of research workers who engage usefully in pure science are scientific *virtuosos*, brimming over with insatiable curiosity. But many of them have other equally valuable personal qualities, such as intelligence or persistence or imaginative insight. Scientific research is much more than the enlightened exercise of personal curiosity. 'Science uses curiosity, it needs curiosity, but curiosity did not make science'[33]. Elaborate intellectual and institutional frameworks are required to harness this individual trait to the collective production of reliable knowledge.

By definition, curiosity-driven research is not intended to be applicable. But its results are often of great practical value. Why, then, is it usually presented as a particularly pure form of basic research – the very antithesis of technological R&D? Surely the world of human artefacts and cultural institutions is full of unexplained phenomena and mysterious patterns. More curiosity may actually be required to make a practical invention than a theoretical discovery. One reason might be that *scientific* curiosity is supposedly focussed principally on the *natural* world. It is aroused by regularities, or by deviations from such regularities, amongst naturally occurring objects, and hence seeks peculiarly 'fundamental' explanations and interpretations [*2.6*, *8.5*].

A more obvious reason is that curiosity is a peculiarly *individualistic* virtue. It goes with the romantic stereotype of the pure scientist as a brilliant nonconformist[34], a 'lonely seeker after truth'. Ideally, the pure scientist is an *amateur*, in the true sense of the word. She plays the research game obsessively, with no other concern than the hope of making a contribution to knowledge. Her purity is moral. It is associated with commitment to a transcendental goal[35] and indifference to such worldly considerations as the possibility of winning a valuable prize or making a commercial profit.

This is how scientists like to see themselves. A sense of personal commitment is still a major element in scientific work[36]. Scientists nowadays can scarcely claim that they are really gifted amateurs. They know very well that they are typical social actors performing a typical professional role. But they are the sort of people who want to be in charge of what they do. They celebrate curiosity because it implies *autonomy*. It can only be exercised by someone who is free to look around them, reflect on what seems strange, and inquire further into it. In other words, by describing pure research as 'curiosity-driven' – even as 'unfettered'[37] – they proclaim that it ought to be undertaken by researchers who formulate their own research problems [*8.1*, *8.7*] and apply their own criteria to what counts as good science.

Basic research cannot be differentiated from other forms of research solely in terms of its psychology[38]. Nor can complete personal autonomy be its sole guiding principle. The image of the pure researcher as a perfectly isolated individual animated by an inner vision is a fantasy. At best, it is a generalized and simplified version of the stories that researchers customarily tell when trying to explain their actions. Such stories are often quite sincere. But they usually systematically ignore the social setting in which these actions are performed. This is the theme to which we now turn.

2.8 Academic science as a culture

Pure, non-instrumental science turns out to be an elusive concept. For policy purposes, it is only a residual category. As a body of knowledge, it is not especially fundamental. It is not always the product of personal curiosity. And yet we have no difficulty in talking about it, and describing some of its typical features. We have a distinct image of an ideal type, even though we cannot target its essence.

This is where naturalism comes to our aid. Pure science, like science in general, is a recognizable natural kind. Instead of trying to define it in the abstract, let us point to it as an existing entity. What we actually have in mind when we use this term is, of course, an extremely familiar and distinctive activity – *academic* science[39]. Pure research is framed by its social setting. It is the type of science that is carried out in universities. The stereotype of the pure scientist is the professor, engaged in both the pursuit of knowledge and its onward transmission.

In effect, academic science is a *culture*[40]. It is a complex way of life that has evolved in 'a group of people with shared traditions[41], which are transmitted and reinforced by members of the group'[42]. That is how it would be seen by a visiting anthropologist from Mars, and that is how it should be represented in our model.

This is well understood by official policymakers. What they sometimes call the *Science Base*[43] includes a mass of research projects, widely dispersed throughout *academia*. When asked to give an account of their support for basic science, they do not laboriously inspect their records, project by project, trying to decide whether it satisfies the Frascati criterion. They simply lump together all the money paid out for 'government funded R&D undertaken within university-level establishments', as if all the scientific activity in these institutions were of the same general type.

In addition – and this is significant – they include under the same heading 'government-funded research in other closely linked, or similar organisations'[44]. In other words, scientific policymakers recognize that this is a distinctive activity which is not confined to educational institutions. Indeed, in some countries, the bulk of academic science is located in separate *institutes* run by a *National Academy, National Centre, Research Council*, or some such bureaucratic organization, with no direct teaching responsibilities. Pockets of the same culture are also sometimes found inside large governmental and industrial *R&D laboratories*. The most notable of these, Bell Labs, was famous both for its Nobel Prizes and for its university-like attitude to research.

Like any other cultural form, academic science has a *history* of development and change. Many of its characteristic features can be traced back to the seventeenth-century Scientific Revolution, or even earlier. It emerged in essentially its modern form in Western Europe in the first half of the nineteenth century[45]. Since then it has evolved into a coherent and elaborate social activity, increasingly integrated into society at large. Indeed, science has grown and spread around the world as a characteristic *subculture* of the general culture of *modernity*. Technoscience [*2.2*] is an essential component of economic development. Although academic science requires a very sophisticated social environment, it is cultivated arduously in tiny plots even in the poorest and least developed countries.

2.9 Many disciplines in one science

Academic science is widely dispersed, geographically and institutionally, and does not have any system of overall control. Nevertheless, it is remarkably open and uniform in its practices and principles. A research scientist can move from university to university, or from a university to a research institute, or even from country to country[46], without serious cultural hindrance. On the other hand, mobility between fields of research is severely restricted[47], even within the same organization. One of the main features of academic science is that it is sharply differentiated and structured in terms of *disciplines* [*8.4*]. A professor of physics in Bristol may have more in common with a physicist in Jakarta than with the professor of chemistry in the next building.

It is worth remarking, finally, that a modern university is expected to be *multidisciplinary*. For educational reasons, it customarily covers as wide a range of disciplines as possible – from Classical Greek Literature, say, to Computational Cosmology. Bundled together arbitrarily into Schools and Faculties, academics of diverse disciplines are driven through parallel career hoops, by the same standardized performance indicators. In spite of vast differences of subject matter their research cultures are stereotyped and homogenized. They are expected to carry out original research, publish their findings in books and articles, be aware of all that is going on and become international authorities in recognized fields of knowledge, supervise the research work of graduate students and post-doctoral assistants, subject their work and career aspirations to the anonymous assessments and public critiques of their scholarly peers, serve as committee persons, editors, referees etc. in their learned societies, seek funds to support their research and the research of their colleagues, attend innumerable conferences, congresses, seminars, workshops and other meetings, give and listen to innumerable indigestible chunks of academic discourse, ask and receive polite but pointed questions concerning their own and other research claims in their specialty – and so on.

The institutional structures that anchor and rule these activities do differ considerably from country to country. British, French and American academics, for example, are indeed heirs to very different intellectual traditions, very different organizational arrangements and very different styles of work[48]. Insiders can even distinguish between apparently identical universities, such as Oxford and Cambridge[49]. But these are only variations on a theme. Such differences are insignificant when compared with life outside the ivory tower, in whatever country.

From this perspective, the differences between the faculties are also insignificant. As academic persons, the professors of physics and chemistry have almost as much in common with the professors of theology and accountancy as they do with each other. The same ideal types, the same social norms and epistemic principles, are deemed to motivate research activity, whether in the natural sciences, the social sciences or the humanities, in management studies or in clinical medicine, in ethnology or in engineering.

In other words, academic science is not restricted to the natural sciences. It includes many distinctive intellectual traditions and disciplines. In some traditions, 'scholarship'[50] – the enlightened re-formulation of existing knowledge – is preferred to 'research' – the generation of new knowledge. Some disciplines are so dominated by their educational and vocational responsibilities that they do not draw a line between original research and exemplary practice. This diversity is a feature of academic science which is sometimes overlooked by policymakers – for example, in the standardized criteria by which they try to measure research performance in quite different subjects.

The grouping of disciplines into Faculties or Schools is a necessary organizational device. But these groups do not separate neatly into just two cultures [*7.10*]. The Continental European usage is justified: the word 'science' should always be interpreted to cover the whole range of organized knowledge. There are, of course, many different 'sciences' – physical, biological, behavioural, social, human, medical, engineering and so on – but they are all varieties of the same cultural species. This is what I mean when I talk about academic science in the rest of this book.

3

Academic science

3.1 The republic of learning

Academic science is the stereotype of science in its purest form. When people talk about scientific research (as distinct from technology) they primarily have in mind the sort of scientific work that is done in universities. They think of it as the characteristic activity of members of a particular social group in a particular social frame.

Scientists themselves insist that they belong to a *community*, indicating that they recognize each other as people who share many values, traditions and goals[1]. But this community is essentially notional. The word is used to mean 'all those people who subscribe to certain general principles of rationality and objectivity, and have such high standards of expertise and mutual trust that they can be relied upon to work together for the benefit of humanity in the attainment of truth'[2]. On the one hand, it proclaims the unity of this group within society at large. On the other hand, it asserts that its members are individuals who are linked together voluntarily by their common attitude to learning and research.

The concept of a scientific community is part of the traditional philosophical Legend. At the same time, however, it encases science in a sociological 'black box', whose internal structure is deemed to be irrelevant to the pursuit of knowledge. Indeed, the power of the Legend lingers on, even amongst the champions of a 'sociology of scientific knowledge'[3]. In effect, they treat the wider institutional frame as the *product* of the processes at work inside the research laboratory, discounting its *influence* on those processes[4].

It is true that the scientific culture fosters rationality [6.8] and relies heavily on trust [5.6]. But the rhetoric of cooperation and fraternity has to be squared with the reality [9.1] that science is also notoriously competitive and disputatious[5]. Scientific biographies are deeply scarred by