The Public Understanding of Science

The Royal Society 1985

The Public Understanding of Science

Report of a Royal Society

ad hoc Group endorsed

by the Council of the Royal Society

ISBN 0 85403 2576

The Royal Society

6 Carlton House Terrace

London SW1Y 5AG

CONTENTS

	Page
Preface	5
Summary	6
1. Introduction	7
2. Why it matters	9
3. The present position	12
4. Formal education	17
5. The mass media	21
6. The scientific community	24
7. Public lectures, children's activities, museums and libraries	27
8. Industry	29
9. Conclusions and recommendations	31
Annexes	
A. List of those submitting evidence	37
B. Visits and seminars	38
C. Selected bibliography	39

PREFACE

This report was prepared by an *ad hoc* group under the chairmanship of Dr W.F. Bodmer, F.R.S.; it has been endorsed by the Council of the Royal Society. It deals with an issue that is important not only, or even mainly, for the scientific community but also for the nation as a whole and for each individual within it. More than ever, people need some understanding of science, whether they are involved in decision-making at a national or local level, in managing industrial companies, in skilled or semi-skilled employment, in voting as private citizens or in making a wide range of personal decisions. In publishing this report the Council hopes that it will highlight this need for an overall awareness of the nature of science and, more particularly, of the way that science and technology pervade modern life, and that it will generate both debate and decisions on how best they can be fostered.

The report makes a number of recommendations. Some of these are addressed to the scientific community itself, including the Royal Society; others concern the education system, the mass media, industry, government and museums. We commend these warmly to the attention of the relevant organizations. The Council of the Royal Society will respond shortly and positively to the recommendations addressed to itself.

A shorter version of the report has been prepared for free distribution in order to ensure the widest possible discussion of the conclusions and recommendations that emerged from the study.

Warm thanks are due to Dr Bodmer and the other members of the *ad hoc* group for their work. We hope that this report will stimulate action aimed at achieving lasting improvements in the public understanding of science.

Professor D.C. Smith
Biological Secretary and
Vice-President

SUMMARY

Science and technology play a major role in most aspects of our daily lives both at home and at work. Our industry and thus our **national prosperity** depend on them. Almost all public policy issues have scientific or technological implications. Everybody, therefore, needs some understanding of science, its accomplishments and its limitations.

Many **personal decisions**, for example about diet, vaccination, personal hygiene or safety at home and at work, would be helped by some understanding of the underlying science. Understanding includes not just the facts of science, but also the method and its limitations as well as an appreciation of the practical and social implications. A basic **understanding of statistics** including the nature of risks, uncertainty and variability, and an ability to assimilate numerical data are also an essential part of understanding science.

A proper **science education** at school must provide the ultimate basis for an adequate understanding of science. There is an urgent need to provide a broadly based science education at school for all to the age of 16, and the resources to make this possible. Much greater priority should, in particular, be given to science courses in all primary schools taught by appropriately qualified teachers. No pupil at school should be allowed to study only arts, or only science, even after the age of 16. A revised system allowing a broader range of subjects to be taken at a somewhat lower level than A-level is urgently needed. Relatively few people trained in science enter generalist careers in, for example, administration or the Civil Service. Yet a good science course provides an excellent training in the skills needed in such careers. Science students and their teachers should recognize that there is a wider market for their skills.

The **Parliamentary and Scientific Committee** could become more effective by, for example, arranging more meetings, at short notice if necessary, to discuss the scientific aspects of issues about to be debated in Parliament. Popular versions of government reports could be made widely available as a matter of course.

There is scope for more **science in the media**, especially in the daily newspapers. Feature articles are particularly valuable because science as such is rarely news. Biographical and dramatic approaches help to show science as a human activity in a historical context. There is also a strong case for including more science in general programmes, and so for improving the contact between scientists and journalists as a whole.

British industries would be more competitive if those who held positions of responsibility had a better understanding of what science and technology can achieve. Scientists involved in research in industry should be encouraged to take wider and earlier opportunities in management positions, helped by appropriate management training. Industry should promote its interests in science education and especially school visits and exchanges. Companies should also inform the public, particularly in their own community, about the scientific and technological bases of their activities.

Scientists must learn to communicate with the public, be willing to do so, and indeed consider it their duty to do so. All scientists need, therefore, to learn about the media and their constraints and learn how to explain science simply, without jargon and without being condescending. Each sector of the scientific community should consider, for example, providing training on communication and greater understanding of the media, arranging non-specialist lectures and demonstrations, organizing scientific competitions for younger people, providing briefings for journalists and generally by improving their public relations.

The **Royal Society** should make improving public understanding of science one of its major activities. Specific initiatives should include briefing seminars and an information service for journalists, help and advice to other scientific institutions on issues such as communication of science to the public, media contact and public relations, and improved contact with Parliamentarians and others at a high level in government and industry. Improving the general level of public understanding of science is now an urgent task for the well-being of the country, requiring concerted action from many sections of society including, most importantly, the scientific community itself.

1. INTRODUCTION

1.1. Science pervades our society. Most of our industry and much of our national prosperity are based on science. In the home as well as at work we use machinery that is the product of this industry. Science affects many, if not most, policy issues of national and international importance. It also affects a wide range of personal activities, from health and diet to holidays and sport. This report aims to show why it matters that all sections of the public should have some understanding of science and to stimulate action by scientists and others to improve this understanding. These are issues with which the Royal Society and many other organizations have long been concerned. They have become important now that science, technology and medicine directly affect, to an unprecedented extent, the details of our daily lives and the prosperity of the nation.

1.2. Public understanding of science has as its base the teaching of science in schools. This report arose from a recommendation in the Royal Society's report *Science education 11–18 in England and Wales*, published in November 1982, that the Council of the Royal Society should set up a small *ad hoc* group to investigate ways in which public understanding of science might be enhanced. This recommendation followed from that report's view that 'a sensible and balanced public view about science education is dependent on the development of much greater awareness and enlightenment about science and its role in society'.

1.3. The Royal Society Council accepted this recommendation and, in April 1983, appointed an *ad hoc* group under the chairmanship of Dr W.F. Bodmer, F.R.S. The members of the Group were Mr R.E. Artus, Sir David Attenborough, F.R.S., Professor R.J. Blin-Stoyle, F.R.S., Sir Kenneth Durham, Sir John Mason, Treas.R.S., Mr M.J. Savory, Lord Swann, F.R.S., Professor Dorothy Wedderburn, Dame Margaret Weston and Professor J.M. Ziman, F.R.S. The Group's terms of reference were as follows:

(i) to review the nature and extent of public understanding of science and technology in the UK and its adequacy for an advanced industrialized democracy;

(ii) to review the mechanisms for effecting the public understanding of science and technology and its role in society;

(iii) to consider the constraints upon the processes of communication and how they might best be overcome;

(iv) to make recommendations and report to Council.

This report of the Group has been endorsed by the Council of the Royal Society.

1.4. The terms of reference raised three problems of definition, namely of 'the public', of 'understanding' and of 'science'. 'Science' we interpreted broadly to include mathematics, technology, engineering and medicine, and to comprise the systematic investigation of the natural world and the practical application of knowledge derived from such investigation. Though technology and engineering have a sense of direct purpose not usually associated with basic science, there is a continuum of activities that extends from basic through strategic to applied research and development. These activities are all based on common underlying scientific principles. Today's basic science is, after all, the foundation for much of tomorrow's technology. 'Understanding' for us included comprehension of the nature of scientific activity and enquiry, and not just knowledge of some of the facts. Clearly, the level of understanding needed depends on the purpose, for example in relation to an individual's occupation and responsibility. Finally, we took 'public' to mean mainly the predominantly non-scientific public. The public can be classified in a variety of ways, for each of which there may be different reasons why an understanding of science is important, and different approaches to achieving it. We considered five overlapping functional categories: (i) private individuals for their personal satisfaction and wellbeing; (ii) individual citizens for participation in civic responsibilities as members of a democratic society; (iii) people employed in skilled and semi-skilled occupations, the large majority of which now have some scientific content; (iv) people employed in the middle ranks of management and in professional and trades union associations; and (v) people responsible for major decision-making in our society, particularly those in industry and government. In chapter two of this report we examine why understanding of science is important for each of these five groups.

1.5. In chapter three we attempt to identify existing levels of understanding. Nearly all relevant published surveys of the adult population are of attitudes to, rather than understanding of, science. These attitude surveys are, however, relevant to public understanding of science and we present a brief review of them. We report what those submitting evidence to us saw to be the state of public understanding of science, and also consider other sources of information, such as Parliamentary debates and audience ratings for broadcast programmes, that have a bearing on public attitudes to and understanding of science.

1.6. The remainder of the report considers ways of improving public understanding of science. The most important of these in the long term is the formal education system, especially at school, which is discussed in chapter four. There are now many new proposals for the teaching of science. Educational reform is, however, necessarily a long-term measure. Other mechanisms that may more quickly achieve improvements in the public understanding of science are considered in subsequent chapters. These include the mass media, museums, industry and the activities of the scientific community itself. Conclusions and recommendations are summarized in the final chapter.

1.7. We hope that this report will stimulate thought and action by those, especially in the scientific community, who are able to promote better public understanding of science. The Royal Society has already taken up some of the initiatives proposed in this report, and can clearly play a major role in helping scientists to contribute more effectively to public understanding of science. Many aspects of the public understanding of science have been considered by others over many years, often with similar conclusions. That agreement only emphasizes the importance of our conclusions and recommendations. The time is now ripe for concerted action.

2. WHY IT MATTERS

2.1. Would the world be a better, or even a different, place if the public understood more of the scope and the limitations, the findings and the methods of science? A basic thesis of this report is that better public understanding of science can be a major element in promoting national prosperity, in raising the quality of public and private decision-making and in enriching the life of the individual. These are nationally important long-term aims and require sustained commitment if they are to be realized. Improving the public understanding of science is an investment in the future, not a luxury to be indulged in if and when resources allow.

2.2. There is a strong *prima facie* case for the existence of a link between public understanding of science and national prosperity, though the link may be as difficult to quantify as that between a company's research and development effort and its overall profitability. Strong economies now almost all depend on a strong manufacturing industry based on science and technology, which are developing at an unprecedented rate. The introduction of new technologies often stimulates major developments in existing technologies, for example, the indirect consequence of the introduction of nuclear power stations in Britain was a substantial improvement in the efficiency of coal-burning power stations. Improvements in existing technologies demand some degree of scientific and/or technical understanding from all concerned—the designer, the operative, the manager and the decision-maker. The new technologies, such as those involved in electronics, synthetic materials, telecommunications or biotechnology, have developed from the underlying science. Their successful exploitation requires those responsible for the nation's industries, as well as a supportive government, to be aware of science and technology, to recognize their potential value and to accept the opportunities they can generate. Successful exploitation also depends critically on the availability of adequately trained and skilled scientific and technological manpower.

2.3. Hostility, or even indifference, to science and technology, whether by shopfloor workers, by middle or senior industrial management or by investors, weakens the nation's industry. Such an attitude appears to be more common in Britain than in our major industrial competitors such as the United States, West Germany and Japan. It is, for example, reflected in a smaller proportion of senior and middle management having a scientific training, and in a less positive attitude by major investors towards the opportunities opened up by technological developments. There would be a considerable competitive advantage if those who hold positions of responsibility had at least some understanding of what science and technology can and cannot achieve, and were better able to call for and evaluate advice on scientific and technological issues.

2.4. There are few, if any, public issues, including unemployment, that do not have a scientific or technical component. Conversely, issues that appear to be largely scientific or technical in nature mostly have major social and political implications. Obvious examples of such issues include disposal of radioactive waste, pollution of the environment, fluoridation of the water supply, whooping-cough vaccine, prescribable drugs and seat belt regulations. There are also many examples of technologically-based policy areas where the political and social elements may be dominant, such as *in vitro* fertilization, the introduction of new technologies in the manufacturing or service industries, defence procurement, overseas aid, land use or fishing quotas. Even the reorganization of the metropolitan boroughs involves scientific issues because of the technical services that they run.

2.5. Science and technology therefore should be major considerations in public policy. Whether they actually are depends on how far *(a)* the decision-makers and their advisers, and *(b)* the public to whom they are ultimately responsible, understand the scientific and technological aspects of each issue and, more generally, the scope and limitations of scientific method. It also depends on the willingness and the ability of the scientific community to explain these aspects publicly. There is clearly a strong case for Parliamentarians, in particular, to have a much better understanding of science and its relevance to their responsibilities than they now have. The scientific community also needs to do much more than it now does help achieve this. Better overall understanding of science would, in our view, significantly improve the quality of public decision-making, *not* because the 'right' decisions would then be made, but because decisions made in the light of an adequate understanding of the issues are likely to be better than decisions made in the absence of such understanding.

2.6. Better understanding of science by government and the higher levels of the Civil Service should also lead to better policies for science. Government needs to appreciate, for example, the interconnections between basic, strategic and applied research, the relative timescales and uncertainties of these three phases, special factors such as increasing instrumental sophistication that affect the cost of research, and the dynamics of the system for financing research in the higher education sector.

2.7. In a democracy public opinion is a major influence in the decision-making process. It is therefore important that individual citizens, as well as the decision-makers, recognize and understand the scientific aspects of public issues. To decide between the competing claims of vocal interest groups concerned about controversial issues such as 'acid rain', nuclear power, *in vitro* fertilization or animal experimentation, the individual needs to know some of the factual background and to be able to assess the quality of the evidence being presented. Wider understanding of the scientific aspects of a given issue will not automatically lead to a consensus about the best answer, but it will at least lead to more informed, and therefore better, decision-making.

2.8. An understanding of science is also important for the individual in his or her private life. Personal decisions, for example about diet, smoking, vaccination, screening programmes or safety in the home and at work, should all be helped by some understanding of the underlying science. Greater familiarity with the nature and the findings of science will also help the individual to resist pseudo-scientific information. An uninformed public is very vulnerable to misleading ideas on, for example, diet or alternative medicine. An enhanced ability to sift the plausible from the implausible should be one of the benefits from better public understanding of science.

2.9. Science and technology influence the individual's daily life in an enormous variety of ways in our gadget-filled, technologically-based society. Ignorance of elementary science cuts off the individual from understanding many of the tools and services used every day. Some basic understanding of how they function should make the world a more interesting and less threatening place. It is obviously not necessary, and hardly possible, for an individual to understand the functioning of everything from a bus to a ball point pen or a television set. But those who have never been stimulated to enquire about how things work and who lack the basic knowledge to pursue such an enquiry are surely at a disadvantage in the modern world. Scientific literacy is becoming an essential requirement for everyday life.

2.10. Understanding the nature of risks and uncertainty is an important part of the scientific understanding needed both for many public policy issues and for everyday decisions in our personal lives. Decisions on nuclear power stations or on medical screening programmes or seat belts or motorway speed limits all involve a balancing of risks, taking into account a variety of social, political, economic and scientific factors. Some sections of the public seem to demand that an industrial procedure or a nuclear power plant is free from risk. But there is no such thing as a zero risk, only a balancing of risks and their costs. A 1:100 000 chance of deformity from a whooping-cough vaccine causes considerable concern, yet parents who for genetic reasons are known to be at risk may often be willing to accept a 1:10 risk of having an abnormal child. There are many examples of issues where to play our role as citizens in a democratic society, or to take in advice that may have a major influence on our personal lives, an understanding of risks and, more generally, of the interpretation of numbers (i.e. statistics) is important. Once again it must be argued that better understanding fosters better public and personal decisions.

2.11. The major findings of science, about cosmology for example, or about evolution, profoundly influence the way we think about ourselves. They are themselves an important part of our culture. Just as one can enjoy music as a listener without being a performer, let alone a composer, so also can one enjoy the excitement and revelation of new scientific discoveries without being a practising scientist. Science has its equivalent of the theatre at the Royal Institution and in television programmes such as *Horizon* and *Tomorrow's World.* Without some understanding of science, an individual is cut off from much of the richness of contemporary human thought. Indeed, whatever the benefits of public understanding of science may be, the intrinsic contribution of science to our culture argues that imparting such understanding is a duty the scientist owes to the public.

2.12. The scientific community, like other parts of our society, has its own culture. The aim of the ablest scientists is mostly to continue to add to the body of scientific knowledge. This is an aim that is often inculcated at the earliest stages of a scientific training, at university or even before. As a result, scientists tend to shun the higher administrative responsibilities of government, Civil Service or industry that would take them away from active research. They thus often remain in research and development, where the rewards in terms of financial gain and overall influence are less, but where the benefit is to remain a practising scientist. That, we believe, is probably the main reason why in this country there are comparatively few people even with a primary training in science in the upper levels of government, the Civil Service and industry. And that in turn is a major contribution to the current lack of public understanding of science. Although it may be difficult to change the culture of the scientist (nor may we want to), we must ensure that those who do achieve such positions of influence, and who do not have a primarily scientific education, nevertheless do have at least some understanding of science. And the main answer to that is to extend and broaden the scientific education at all levels. This must be the eventual way to overall improvement of public understanding of science, as we discuss in chapter four, after first reviewing the present situation.

3. THE PRESENT POSITION

General

3.1. There are many surveys of *attitudes to* science and technology both in the UK and overseas, especially in the USA. But there has been much less effort outside the formal education system devoted to assessing the *understanding of* science and technology. Research is needed on how to measure public understanding, so as to enable monitoring of whether particular actions have changed public understanding of science, and whether such changes in fact bring about thei. intended consequences. For example, do firms whose directors, middle management and workforce have a better understanding of science perform better in a technologically competitive setting? Do individuals with more understanding of science use this understanding in making personal decisions or in formulating their attitudes on public policy issues? **We recommend that the Economic and Social Research Council (ESRC) and other appropriate bodies sponsor research into ways of measuring public understanding of science and technology and of assessing the effects of improved understanding.** A related question is: from where do individuals obtain their information? Is it, for example, mainly at school, from television, radio and newspapers, at work, from leisure activities, from magazines and books or from museums and other sources? What is the balance between these sources for different segments of the public? These are important questions to answer in order to make best use of limited resources for increasing public understanding. **We therefore also recommend that the sources from which individuals obtain their understanding of science be actively investigated.**

3.2. Adequate public understanding of science depends at the very least on adequate levels of literacy and numeracy. There is good evidence that, for a significant portion of the British population, these do not exist. The Adult Literacy and Basic Skills Unit published in 1983 the findings of a survey of 12 500 23-year-olds which indicated that, in the UK as a whole, there are some 2–3 million adults who cannot read or write properly and some 1–1.5 million adults who find difficulty doing simple arithmetic, with only slight overlap between the two groups. There are thus some 3–4 million adults who lack the basic skills of literacy and numeracy without which it is difficult to acquire much, if any, understanding of science. **Renewed efforts to improve adult literacy and numeracy are an essential element in improving public understanding of science, as, indeed, they are essential to many other aspects of modern life.**

3.3. Our assessment of the present nature and extent of public understanding of science included examination of existing surveys of public attitudes, which provide information that is clearly relevant to our main concern. We also invited and received evidence from numerous organizations and individuals (listed in Annex A) as to how they perceive public understanding. In addition we sought evidence, for example, from parliamentary debates and the language of advertising about how the public reacts to particular scientific issues, and how it accepts or rejects pseudo-scientific claims.

Surveys

3.4. Major surveys of public attitudes to science have been carried out by the Commission of the European Communities (CEC) and by American organizations. The CEC has so far published the results of four surveys, each involving representative samples of about 1000 adults in each of eight countries of the European Community and about 300 adults in Luxembourg.

3.5. The first CEC survey, published in 1977, covered 'Science and European public opinion'. This found a strong consensus on a range of issues, irrespective of nationality, age, educational background or political views. For example, the public thought that science had been and would continue to be one of the most important factors in the improvement of daily life, although recognizing that science could also have very dangerous effects. Favourite areas for increased research effort were those related to immediate human welfare, especially medical science and food production. Favourite areas for reduced effort were, by contrast, those remote from most people's daily experience, namely space exploration and defence research. Of the sample surveyed 66% expressed interest in media output on science. The survey concluded that, in principle, there was no crisis of confidence in Europe with regard to science.

3.6. A similar survey two years later looked at attitudes to scientific and technical development and, as in 1977, found a high degree of interest among those interviewed. People interviewed generally wanted to know more about science, to have a better grasp of the details of scientific and

technical developments and to be more involved in formulating national research policy. Science was seen as continuing to be beneficial in the future, though this perception was coupled with anxiety about increasing potential risks. The distinction was drawn between science (good in itself) and its applications (sometimes put to use without adequate thought). In the UK those interviewed were less likely than most to agree that 'it would be a good thing if the construction of so many machines could be stopped and we could go back to nature'. Of the total sample 80% was 'really concerned' about environmental pollution, 67% about automation and unemployment, 53% about the risk of medical or pharmaceutical discoveries accidentally damaging human personalities severely and 53% about the increasing impact of 'artificial things of all sorts' on daily life. There was greater diversity among member countries than in 1977 about the priority of different research programmes. In the UK those interviewed thought it 'worthwhile' to continue research as follows:
—organ transplants: 82% (to improve lives of handicapped) (EC average 82%);
—new sources of energy: 76% (largely to avoid over-dependence on nuclear power) (EC average 76%);
—synthetic materials: 63% (to conserve natural raw materials) (EC average 54%);
—nuclear power: 57% (to ensure electricity supply) (EC average 44%)
—more observation satellites: 55% (mostly for mineral exploration) (EC average 55%);
—synthetic food: 34% (to alleviate world hunger) (EC average 23%);
—genetic research: 32% (to improve the qualities of domesticated and economically important plant and animal species) (EC average 33%);
—centralization of information about individuals by computer: 15% (for administrative efficiency) (EC average 22%).

3.7. The two remaining CEC surveys were focused on more specific issues: energy (1982) and the environment (1983). The energy survey found a fairly superficial awareness of the risks of a breakdown in energy supply, coupled with a strong emotional attitude to energy issues. The most favoured options were increased research in renewable energy sources, then increased exploitation of existing sources, then energy-saving schemes, then nuclear power. An interesting finding was that the public took a poor view of the information on energy problems offered to them by the press, radio, television and educational bodies, and indeed tended generally to blame the mass media for their own ignorance. The environment survey reported that Europeans consistently placed a high priority on environmental issues (nature conservation and pollution control). Most Europeans were content with their local environments but very concerned about the national and global environments. In the UK the level of concern was slightly below the European average on all issues except nuclear waste disposal.

3.8. An interesting, if unrepresentative, survey was conducted in the UK in 1975, when 1228 *New Scientist* readers and 331 *New Society* readers filled in a one-page questionnaire about their views on what scientists are. The outcome was a mixed bag, with scientists seeing scientists as typically approachable, sociable, open, unconventional, socially responsible, and popular with broad interests, while non-scientists saw scientists as typically the opposite. Objectivity was generally agreed to be a characteristic of scientists, though the survey concluded that this was partly a myth projected by scientists to the public. A majority of both pro-science and anti-science respondents thought that scientists were respected by the public. Individuals most often named in answer to 'When I think of a scientist, I think of ...' included Archimedes, Professor Branestawm, Bronowski, Einstein, Faraday, Newton, Magnus Pyke and Barnes Wallis.

3.9. More recently, *New Scientist* commissioned an attitude survey by Gallup of a nationally representative quota sample of adults (see its issue of 21 February 1985). The general findings, in terms of esteem for science and priorities for research, were broadly similar to those of the 1977 CEC survey. In contrast to the situation in the USA (paragraph 3.11 below), however, science was ranked below not only medicine but also the armed forces and the law as a social institution whose leaders were trusted by the public. Among the most interesting findings were that 89% of respondents agreed that everyone should study at least some science up to the age of 16, 84% agreed that 'scientists and technologists should pay more attention to the social implications of their work', and 76% agreed that 'politicians should know more about science and its applications'. The latter point could also be applied to the respondents themselves: 36% could not name a major postwar scientific achievement and 47% could not name three past or present major scientists.

3.10. In the USA more effort has been made than in Britain to survey public attitudes to science.

A poll conducted for the National Science Foundation in 1972 found generally favourable attitudes towards science and its ability to solve national problems. Of the sample, 49% expressed 'satisfaction and hope', 23% 'excitement or wonder', 6% 'fear or alarm', 6% 'indifference' as their dominant emotion towards science and technology; 30% thought science could solve most, 47% some and 16% none of the major problems of society (such as pollution, drug abuse, crime); 48% thought science caused some, and 7% most, of society's problems. Research objectives given highest priority were health, crime and pollution; the pursuit of fundamental knowledge came near the bottom of the order of priority. It is significant that health, crime and pollution were also identified as priority areas for general public expenditure, so it may be that the public simply transfers to science its overall hierarchy of concerns without particularly understanding what science might be able to contribute to them.

3.11. In the USA there was, apparently, an erosion of public appreciation of science in the early 1970s. Polls during the 1950s and 1960s showed buoyant support for science, mainly on account of its ability to achieve desirable goals rather than for its inherent interest. The subsequent drift in support was, however, parallelled by loss of confidence in public institutions generally; indeed, against this background of generally declining confidence, science rose from fourth place to second (below medicine) in the list of most trusted institutions. Unqualified support for science certainly declined. By the late 1970s scientific research seen as increasing individuals' control over their own destiny was welcomed, but research that might decrease personal control was not. There was a strong preference for applied over more fundamental research. In 1976 only 9% of the general public saw fundamental research as a priority for science and technology expenditure (down from 21% in 1974 and 19% in 1972).

3.12. One of the most thorough surveys of public attitudes to science in the USA is that conducted for the biennial report *Science indicators* published by the National Science Board. The most recent available survey (1982) categorized respondents as 'attentives' (the 20% of the total sample that was most interested in and knowledgeable about science), 'potential attentives' (the next 20%, interested but less knowledgeable) and 'non-attentives' (the remaining 60%). The survey also included a group of non-government policy leaders in science and technology. Of the 1982 sample 74% thought the beneficial consequences of scientific research had outweighed the harmful consequences (attentives: 90%; potential attentives: 79%; non-attentives, 66%). A different poll, however, found 56% of the public agreeing that 'science and technology do as much harm as good' and 77% agreeing that 'science and technology often get out of hand, threatening society instead of serving it'; 42% agreed that 'scientists can solve any problem we might face if they are given enough time and money'. The data presented in *Science indicators 1982* point to two conclusions: that those closest to science have both the warmest appreciation of its value and the clearest understanding of its limitations, and that the findings of a poll asking essentially whether science is 'a good thing' depend critically on the precise phrasing of the question.

3.13. The more pro-science attitudes of those closest to science are apparent from questions about funding. *Science indicators 1982* found that 49% of attentives wanted more federal spending on general scientific research as a matter of priority, compared with 35% of potential attentives and 25% of non-attentives; 64% of attentives, 53% of potential attentives and 45% of non-attentives wanted more federal spending on research into ways of providing and conserving energy. Additional funding for space exploration was supported by 39% of attentives, 24% of potential attentives and only 10% of non-attentives. Non-government science policy leaders identified the three most important issues in science policy as increased funding for basic scientific research, better public understanding of science and improved school science education (in that order). Like their European counterparts (paragraph 3.5 above), the American general public identified food and medical issues as areas of high priority for scientific research.

3.14. American survey data are not necessarily relevant to Britain. Nevertheless public attitudes to science appear to be similar in the two countries. Survey data are notoriously difficult to interpret and, as already emphasized, depend critically on the way questions are asked. On the evidence presented above it appears that the 'general' public: is interested in science and would like to know more about it; tends to over- estimate the ability of science to solve what are essentially social problems; gives higher funding priority to applied than to fundamental research (though some areas of fundamental research, such as astronomy and cosmology, generate great public interest); and, generally, is guardedly supportive of science while being wary of some of its applications.

3.15. The public attitudes to science revealed by surveys may be a valuable guide to the improvement of understanding. Areas of concern and interest, as well as deficiencies in knowledge and understanding, are identified. The contrast between, for example, the support for basic research given by those with more, as compared with less, knowledge of the science, emphasizes the need to explain the extent to which basic research underlies the technological advances of the future. The obvious interest in issues such as energy supply and pollution emphasizes the value of relating the teaching of, and the provision of information about, science to these issues. **We recommend, therefore, that the Economic and Social Research Council and other appropriate bodies devise methods of monitoring attitudes to science in the United Kingdom along the lines of the USA National Science Board's *Science indicators*.**

Other evidence

3.16. Nearly all the evidence submitted to us came from individuals or organizations professionally involved with science. Not surprisingly, this evidence unanimously argued, in a variety of different ways, that public *understanding of* science was inadequate. This contrasts with the considerable public *interest in* science revealed by the findings of the opinion surveys mentioned above and by the proliferation of popular technical magazines and hobbies.

3.17. There was said to be much less understanding of the nature of scientific activity than knowledge of scientific facts. The scientific generalizations that convert accumulations of facts into insights about the natural world need to be better understood. Neither the principles nor the limitations of scientific method were thought to be familiar to the general public. There was little understanding of basic scientific concepts such as causality and probability, and not much grasp of the quantitative aspects of science. Non-scientists were said often to find it difficult to understand data presented statistically or to grasp the intrinsic variability of natural phenomena. This is another reflection of the lack of understanding of risks, probability and statistics already mentioned in paragraph 2.10.

3.18. Scientific research was often said to be seen as a simple logical process producing unequivocal answers. Scientists, by the same token, were seen as logical and unemotional individuals removed from the messiness of 'real life'. One corollary of this is that lack of unanimity among scientists on a given scientific issue may be used to obscure and distort the scientific contribution to public debate. Another corollary is that science, as the apparent purveyor of certitudes, may sometimes be accorded inappropriate support and prestige for issues to which there is no simple answer. Quick 'technical fixes' may be demanded, such as for 'acid rain' where there is still inadequate basic understanding of the factors, let alone a simple approach to a solution; then, when the effects of an action take some time to be assessed, public impatience may easily lead to an inappropriate and premature change in tactics. A third corollary is that this view of scientists as purely logical and unemotional not only detracts from a balanced view of the scientist as an ordinary person but also may preclude recognition of the imaginative and humanistic aspects of the scientific endeavour. A fourth corollary is that people who believe themselves to be incapable of following a mathematical argument may tend to regard science as impenetrable and probably irrelevant for them. It was suggested to us that the stereotype public view of the scientist meant that the British Association Young Scientists sometimes finds the term 'young scientists' a barrier to recruitment.

3.19. Some of those submitting evidence to us emphasized the generally poor understanding of science among many Parliamentarians and their advisers, especially in the House of Commons. Parliamentary debates in the Commons on issues such as fluoridation of the water supply, *in vitro* fertilization or disposal of radioactive waste (to mention but three issues debated during the first quarter of 1985) have been characterized in general by a serious lack of understanding of the scientific aspects of these issues. On the other hand, some government reports such as the original 1975 Ashby Report on genetic manipulation, the Warnock report on *in vitro* fertilization and several recent reports from the House of Lords Select Committee on Science and Technology make a substantial contribution to public understanding and the debate of scientific issues. **It would be useful if 'popular' versions of such reports could be made widely available as a matter of course.**

3.20. The connections between scientific research and its applications are often ignored or misunderstood. There is much support for socially desired goals, such as new drugs, the medical use of radioactive isotopes and the alleviation of infertility, but opposition to the scientific techniques that make them possible, namely animal experiments, nuclear reactors and human embryo research.

The ends are willed but the means are not. Sometimes, of course, the ends may not be deemed sufficiently important to justify either socially or morally the means through which they can be realized. That is for the public, for society as a whole, to decide. But unless the essential relation between means and ends is understood and the basic scientific background explained, a balanced judgement cannot be achieved.

3.21. A further problem that arises from the relative lack of public understanding of science, and especially its statistical aspects, comes from the demand for absolute safety in areas such as pharmaceuticals or nuclear power stations, already referred to in paragraph 2.10. This contrasts with popular acceptance of much lower safety standards in, for example, private transport. There are many possible reasons for these contradictory views, including beliefs about the power of large organizations and the freedom of the individual. But a major contribution comes from the mistaken impression that science and technology are able to deliver absolute safety, reinforced by a lack of knowledge about the comparative risks of different products or activities, as well as a lack of understanding of the nature of risks. How many people realize that, as Richard Peto has put it, of 1000 young people who smoke cigarettes regularly, on average one will be murdered, six will die in traffic accidents and 250 will die prematurely from smoking cigarettes?

3.22. Advertisements, designed by people whose professional responsibility it is to know how to appeal to the public, often invoke science. Domestic appliances are described as 'the appliance of science', cosmetics are 'the science of beauty', detergents are 'biological', washing-up liquids are 'scientifically proven' to last longer, motor cars are 'designed by lasers' and sold on slogans like 'man and machine in perfect harmony'. Such propaganda, though they may not be taken at face value, suggest that, at least in some contexts, 'science' conveys the notion of something desirable, even if poorly understood.

3.23. There is much evidence for a considerable public interest in science, as already emphasized, notwithstanding the apparent lack of public understanding of scientific principles and knowledge of scientific facts. There are, for example, large audiences for programmes like *Tomorrow's World* (average 9.2 million for the 41 programmes in 1982–83), *QED* (average 7.7 million for 14 programmes in 1982–83), *The show me show* (average 5 million), *Your Life in their Hands* (average 5.5 million), *Horizon* (average 3.5 million) or *Medicine Now* (average 1 million). The Science Museum, London, has about 3.5 million visitors annually and the British Museum (Natural History) has about 2.5 million. The British Association Young Scientists has nearly 10 000 members. Such widespread interest gives a foundation on which to build.

4. FORMAL EDUCATION

4.1. A proper science education for all must be the starting point for any attempt to achieve a level of public understanding of science adequate to meet the requirements set out in chapter two. The formal education system is defined here as covering the primary and secondary stages of compulsory education, and the routes to, and participation in, further and higher education including sixth-form colleges, vocational training, universities, polytechnics and colleges of technology. The Royal Society has already, in December 1981, published a major report on science education for ages 11–18 (see paragraph 1.2 above). We have taken the arguments and conclusions of that report as a starting point for the present study. This, and many other reports on science education, have led to a consensus on a variety of issues, including (i) the need for a balanced education in science for all to the age of 16; (ii) a broadening of the curriculum; (iii) an emphasis on principles as well as facts; (iv) the need to include the practical applications and social implications of science; (v) better resources for science teaching; (vi) better provision of in-service training; and (vii) improved schools–industry liaison. These are all recommendations that we fully endorse. Here we shall emphasize those areas where consideration of the long-term requirements of the public understanding of science, as discussed in previous chapters, particularly affect the teaching of science in the formal education system.

4.2. The formal education system should provide all members of society with the base of knowledge, skills and understanding on which their subsequent development at home and at work will build, irrespective of subject or occupation. The progress of scientific understanding, the changes in the scientific and technological base of industry and the increasing involvement of the public in national decision-making mean that education given early in life, while providing the basis for an individual's future ability to acquire scientific knowledge, cannot it itself suffice for a lifetime. Furthermore the formal education system cannot quickly bring about a general raising of levels of understanding throughout the population. The changes to the school curriculum that we may recommend should result in the majority of the population having a firm grounding in mathematics, science and technology, but only in 30–40 years' time. We therefore believe that other more immediate actions, which should benefit present as well as future generations and which are described later in this report, must be urgently implemented. The longer-term educational reforms we now discuss must also be pursued urgently hand-in-hand with the more immediate initiatives.

4.3. The aims of the formal education system in relation to science include:

(i) to develop the processes of scientific thinking in the context of a broad education—observing, pattern seeking, explaining, experimenting, communicating, applying;

(ii) to acquire a range of mental and manual skills through direct involvement in scientific activities;

(iii) to acquire some knowledge and understanding, through systematic study, of the body of knowledge called 'science';

(iv) to understand the nature of an advanced technological society, the interaction between science and society and the contribution science has made, and can make, to the cultural heritage.

All these aims contribute to providing a foundation for understanding science in relation to an individual's personal, working and social life.

4.4. The following principles form a basis for the overall science curriculum to age 16:

(a) all pupils should follow a broad, coordinated science curriculum embracing the three traditional branches (physics, biology and chemistry) and their interrelations, as well as other sciences such as the Earth sciences. Teaching should be coordinated and practical, drawing extensively on examples from everyday life and industry to make the science interesting and relevant to pupils' present and future lives;

(b) the teaching of science should impart not only knowledge of scientific facts but also familiarity with scientific method, the nature and limitations of scientific method and knowledge, the history of science and the social roles of science and technology;

(c) the teaching of science must relate more closely to its applications and its implications: it should impart awareness of and stimulate interest in technology, which may be defined as practical problem solving based on scientific principles, circumscribed by economic, aesthetic and social considerations;

(d) the teaching of technology and the solving of technological problems should be part of science

teaching in addition to arising elsewhere in the curriculum (e.g. in Craft, Design and Technology). It should emphasize the practical approach to problem solving, with a clear intent to produce relevant and appropriate solutions to real problems. Not only should the science and craft aspects be covered but also the economic, social and utilitarian aspects of both the problem and its solution;

(e) mathematical education should aim to bring about confidence in numeracy, a firm understanding of the use of mathematical methods and experience in the representation of events using the symbolic and abstract forms of mathematics. Mathematics teaching for the average pupil should, however, be based firmly on practical and relevant examples and the need for numeracy;

(f) some understanding of statistics, including the ideas of risk, uncertainty, ratios and variability that are intrinsic to the scientific method should be a goal of all science courses—statistics should not be regarded as simply an abstract element in the mathematics course. At its simplest, statistics is an extension of numeracy. It can readily be made interesting and relevant by relating it to the problems of everyday life. **There is still a need to develop new materials for the teaching of statistics to all pupils up to the age of 16.**

4.5. These principles, as mentioned in paragraph 4.1, are broadly supported by many reports and organizations, including: the Department of Education and Science (DES), in its consultative documents on science education (1982) and on the 5–16 curriculum (1985) and its policy statement on science 5–16 (1985); Her Majesty's Inspectorate (HMI); the Association for Science Education (ASE) in its policy statements (1979, 1981); the report of the Cockcroft inquiry into the teaching of mathematics (1982); and the House of Lords report on education and training for new technologies (1985). There are also at present a number of national and regional initiatives directed at new developments in the science curriculum, including the Secondary Science Curriculum Review (SSCR), the Technical and Vocational Education Initiative (TVEI) and curricular experiments such as the ASE's Science in a Social Context (SISCON).

4.6. Schools often compartmentalize science, for reasons of timetabling and teachers' training, but this must not prevent scientific matters from appearing throughout the curriculum. Scientific topics can, for example, be introduced in English essays to allow pupils with a scientific inclination more scope for self-expression. Pupils should also learn to write about science in good, clear English free from jargon. Examples from science and technology can enrich language, history or geography classes, presenting a broader view of the subject to all pupils and helping to integrate science into the overall cultural scene.

4.7. Science and technology education must start at the primary level where an excellent foundation can be laid for future understanding in the secondary school. Observation, exploration, problem solving and practical involvement are the principles of an integrated project-based approach, unencumbered by the subject divisions encountered later. The HMI report on primary science (1983) sets excellent guidelines for effective science-based work for pupils at this age. There are, however, major constraints to the spread of good science teaching in primary schools. Preparing a good project requires a large amount of time and materials, of workcards, project tables and samples. Many primary teachers lack confidence in their own scientific and mathematical training or even lack that training at all. All primary teachers should have some basic training in science and mathematics. Life-long attitudes to science are often established at this early phase in a person's development. **We recommend that much greater priority be given to laying the foundations for a sound understanding of science through appropriate science courses in all primary schools.**

4.8. The Assessment of Performance Unit (APU) has undertaken very useful studies into pupils' views of and achievements in science and mathematics. Girls especially fail to participate and achieve, notably in the physical sciences and mathematics, and this is reflected in the relatively small numbers opting to follow physical science after the age of 13. There are, however, recent encouraging signs of improvement in this direction. 'Science for all' will only have an effect on the eventual understanding of science if it is made appealing, exciting and relevant for the vast majority of the pupil population.

4.9. Good science teaching for all at school depends on an adequate supply of good, dedicated teachers. In the physical sciences and mathematics there is already an outright shortage of teachers, both in service and in training. The scientific culture, discussed in paragraph 2.12, undoubtedly has its effect on the supply of good science teachers. Those who follow a scientific training often want to pursue a career in research, and consider teaching as at most a second-best option. This problem is compounded by the relatively poor salaries of science teachers as compared to opportunities for scientists elsewhere, especially in industry. This situation appears to be less critical for graduates in the arts, humanities, social and perhaps biological sciences. The pool of entrants to science teaching, especially in physical science and mathematics, thus includes relatively fewer highly qualified people than for other subjects. A highly qualified scientist does not necessarily make a good science teacher, but a normal school science department requires a balance of well-qualified graduate specialists with a flair for science to cover the full spectrum of science in the curriculum. All science graduates should bring to their teaching the insight and excitement that are the basis for stimulating children to have an interest in science.

4.10. Teacher training rarely provides experience of work outside the education system, particularly in commerce or industry. But if science and mathematics are to be, and to be seen by pupils to be, useful bases for future life then they should relate to the needs of pupils for their future work. And for this an appreciation of industry and commerce is essential. Such appreciation can only really be obtained by direct experience. There is an increasing number of opportunities to gain experience in industry through fellowships and secondments and this trend should be strongly encouraged. Such exchanges should help to erode the widely perceived antagonism to commerce and industry in our overall education system. There is a good case for more teachers, between finishing their first degrees and starting teacher training, having experience of work outside the formal education system.

4.11. Refresher courses are needed periodically to update teachers' knowledge of new scientific discoveries and techniques throughout their teaching career. The current revisions of science curricula will also bring in topics not previously included and these need to be covered. In-service courses for teachers have traditionally been provided for such purposes, but regrettably only a minority of teachers see these as an essential part of their continuing training. It is important, however, that active scientists are involved in these in-service courses to ensure their relevance and quality. **Attendance at in-service courses should form an integral part of teachers' conditions of service and should not be seen as an optional extra for enthusiasts.**

4.12. A broader appreciation of the role of science and technology in society can be achieved by courses of the type developed under the SISCON project, and we recommend that greater use be made of such courses. A broader appreciation can also be brought directly into schools by individuals coming to speak about their work and by pupils' visits to factories and laboratories. Visiting speakers and visits by pupils can convey the excitement and prospects of working with science and technology, whether as research scientists, technicans or managers. **We recommend that industry and schools extend the range of opportunities for exchange—teachers into industry and industrialists into schools—to broaden their contacts and increase the technological and industrial relevance of the science taught in schools.** It is important that teachers are not prevented from accepting secondments to industry by a lack of funds at Local Education Authority level.

4.13. There are already many encouraging changes in schools in these directions. Science clubs, the British Association Young Scientists (BAYS), the Young Engineering Clubs being established by the Standing Conference on Schools' Science and Technology (SCSST) are all valuable extracurricular activities to encourage pupils, and to broaden their experience still further. The Science and Technology Regional Organizations (SATROs) of the SCSST are providing useful assistance to schools in their areas and there are indications that this will increase on a national basis.

4.14. Education in this country for pupils over the age of 16, especially in the sixth form, is appallingly narrow. It is not even possible at A-level to cover all the sciences, let alone some reasonable combination of arts, science and humanities subjects. **No pupil at school should be allowed to take only arts or only science subjects even after the age of 16. The depth of specialization entailed by the current A-level system is totally unnecessary, often engendering wasteful repetition of subjects in the first year of a degree course. A revised system, allowing a broader range of subjects to be taken at a somewhat lower level, is urgently needed.** Only in this way can we hope to achieve the broadening of our educational system that will, as discussed in paragraph 2.12, ensure at least some scientific literacy among all our leaders in central and local government, the Civil Service, industry, commerce and elsewhere in society.

4.15. **To achieve the goals set out above for an appropriate science education for all, extra resources must be made available.** These are needed, above all, to provide a proper supply of good and dedicated science teachers at all levels, from the primary school to the sixth form. They are also needed to support increased provision of in-service training, to enable new teaching texts and materials to be produced to suit the new courses, and to provide equipment, laboratories and laboratory staff to cater for the larger numbers studying science. Teachers will also need time to plan the proper introduction of these courses, given that they are already having to cope with many other curricular and examination changes.

4.16. Higher education institutions in practice restrict the potential for broadening sixth form education by continuing to demand unnecessary and unreasonable levels of specialization before entry into a degree course or its equivalent. The claim that such a broadening will degrade the quality of a university education simply cannot be sustained in the face of the obvious adequacy and, indeed, considerable success of, for example, the American, West German and French systems, which do allow for continuing breadth of education up to and even including the university level. **University teachers, especially of science subjects, must be persuaded of the overall value to our society of a broader post-16 educational system.**

4.17. There is scope for some broadening of university and public sector higher education itself to include combined arts and sciences courses. Universities seldom give strong encouragement to students to study outside their chosen subjects and even less between faculties. We see little opportunity for major changes in this, as courses, especially in the sciences and engineering, are already severely overloaded. The 1980 Cairncross report, *Science studies*, gave a valuable analysis of both the opportunities and the difficulties. **We urge universities to introduce general studies or find some other way for undergraduates to benefit from the presence in the same institution of experts in subjects outside their own courses of study.**

4.18. Science students, as already discussed in paragraph 2.12, are led to think of their studies as a means to becoming 'professional scientists', namely academics or research workers in industry or government research establishments. University courses mostly reinforce this view, and seldom demonstrate the broader value of a science degree in management, administration, teaching, marketing, indeed in any other walk of life. Though this tendency may be changing, it is in marked contrast to the arts or social sciences, where few students see their careers as being in their chosen subject of study. University science students should, in general, be urged to consider a science degree as much a general training as do their arts student counterparts. Likewise, those responsible for recruiting graduates to industry, the Civil Service and other areas of employment for careers in management, administration and other generalist functions should recognize the general educational value of a science degree and not regard it as solely a route to jobs requiring particular specialized skills. This must not and need not, of course, be at the expense of providing enough skilled manpower for the needs of our technologically based society, in particular in industry.

4.19. The progress of science is such that, as mentioned in paragraph 4.2, education at school and even at university cannot suffice for a life-time. Many people, not only science teachers at school, will need to update and refresh their knowledge of science and technology periodically throughout their lives. For this, a system of continuing and further education that adequately covers scientific subjects is essential. Many institutions, including the universities themselves, make significant contributions to such education, and this should be strongly encouraged for the science and technology areas. The Open University and the BBC show how effectively distance learning techniques (i.e. the use of radio, television, tapes and computers) can contribute to science education, especially in continuing and further education. The opportunities for such approaches are likely to expand rapidly in the future with the wider use of video cassettes, recorders and the advent of cable and satellite television broadcasting. **New approaches to continuing and further science education should be developed.**

5. THE MASS MEDIA

5.1. The media can exert a powerful influence on public understanding of science. The scientific community traditionally regards the mass media with some suspicion and is, on the whole, ignorant of the way they work and the nature of their constraints. The more 'popular' sections of the media, on the other hand, too often make relatively little effort to discuss science in anything other than a superficial and mostly sensational way, and do not generally understand the nature of the scientific enterprise. These attitudes need to be changed. To do so will require a considerable but challenging and worthwhile process of mutual education.

5.2. The main explicit function of a scientist is to generate knowledge about the natural world, whether for its own intrinsic interest or for some immediate or future practical application. Success is judged mainly by the approval of other scientists or by the usefulness or commercial success of the application to which the new knowledge gives rise. The main functions of the media are to entertain and to inform. Success is judged primarily by audience ratings (numbers and level of appreciation) or circulation figures, which, for the commercial parts of the media, translate into profit. Each group needs to recognize how the other can help it achieve its objectives and to understand each other's limitations.

5.3. Research scientists generally work only in disciplines that they thoroughly understand already, or hope to understand. Their deadlines for producing results, such as published papers or presentations at scientific meetings, are relatively relaxed. There are few serious limitations on the number of words they can use to describe their findings, so they are able to report their work in detail and indeed are encouraged to do so. The questioning nature of a scientific training tends to produce formal discussions of all the uncertainties of an analysis. Scientists generally speak to a well-defined audience with similar interests to their own, and are therefore able to use their own specialized language. Research papers are considered for publication and edited by people who are familiar with the subject and are basically sympathetic to the researchers' aims.

5.4. The mass media, especially the news media, operate in a very different, almost diametrically opposite way. Each reporter usually has to cover a very wide range of activities, few of which will be initially familiar. Copy has to be produced to fit in with the tight production schedules of daily or weekly publications or broadcasts, and to fit into the very limited space available. It has to be in language suitable for a diverse general audience avoiding complicated jargon and to hold that audience's attention in competition with other items. Most difficult of all, the science journalist has to assimilate information generated by someone else, turn it into a form suitable for a publication or programme, and persuade a news editor, who is unlikely to have a scientific background, that his own item has better claims for inclusion than other items that may be more familiar to the editor. If the item successfully negotiates these hurdles, it is then given a headline and cut to fit the space or time available by a sub-editor who, like the editor, is unlikely to know much science.

5.5. A reasoned well-qualified scientific statement does not easily fit into such a pattern, nor does it provide an eye-catching headline. The whole process of reduction of the scientific information to a manageable form by the science journalist is almost bound to lead to some distortion, thus fuelling a distrust of the media by scientists. These problems are further aggravated by the inevitable choice of sensational news items, often either catastrophes, such as the Bhopal disaster, or 'breakthroughs', for example involving a new drug or cancer treatment. The scientist does not want always to be represented by such items. The catastrophes do not, fortunately, represent everyday scientific activities, and the supposed 'breakthroughs' are often false alarms. Science as such is rarely news. Each small new step forward depends on many previous advances. The adversarial style in which much political commentary is presented, where direct conflict between opposing views on a particular issue is actively encouraged, is also alien to the scientific process. Controversy in science has its own peculiar style and conventions. It usually involves detailed argument and counter-argument, rather than, as in politics especially, confrontation, often fuelled by emotion and rhetoric. If scientists are to communicate with the public through the media, they must, however, learn to accept the media's constraints and to convey information on the journalists' terms. The science journalists, on the other hand, who may not themselves be scientists, have to understand the scientists' attitudes. The science journalists' major constraint, however, is often an editor who undervalues the contributions of science and the interest his readers have in science.

5.6. Features are less constrained than the news media. They include programmes such as

Horizon, *Tomorrow's World* and *QED*, the 'Futures' section of *The Guardian* and similar sections in, for example, *The New York Times*, longer articles in the Sunday papers and special sections of weekly magazines such as *The Economist*. In producing features the journalist has much more time to assimilate the background, more space in which to put over a story and less competition from completely different sources. The scientists themselves can also often be involved in or contribute to features. Nevertheless, the limitations are still much greater than those facing scientists when communicating with other scientists. There is much less space or time available and the language must be simple, free of jargon and intelligible to the general lay public.

5.7. Science appears in many broadcast programmes or newspaper articles that are not specifically identified as science items. This is most obvious for news and news features, such as *Panorama*. But science-related topics can appear almost anywhere in items on, for example, industry, commerce, computing or health care problems and in drama from *The Archers* (on farming) and detective thrillers to science fiction, including *Dr Who*. Scientists are, however, rarely involved in current affairs programmes, interviews or chat shows, such as *Stop the Week* or *Any Questions*. As a group they undoubtedly tend to shun such appearances. But the relative under-representation of scientists on such general programmes mostly seems to reflect a lack of willingness by the producers to accept science and scientists as an integral part of our culture. **There is a strong case for including more science in general programmes**. Such subliminal sources of scientific information can make a significant contribution to public understanding that extends well beyond overtly scientific items. But their scientific accuracy and quality are much harder to monitor. Professional science journalists are rarely called on for help in such items by their non-science colleagues. These latter also have much less contact and familiarity with the scientific community, and so are much more liable to make mistakes and unwittingly distort or misrepresent scientific issues. **Mechanisms need to be found, therefore, for improving the contact with scientists and the understanding of science, not only by science journalists, but also and perhaps even more importantly by journalists as a whole.**

5.8. Science is, in general, much less well represented in newspapers in this country than it is on the broadcast media. This appears to be the fault not of the science journalist, who generally does a good job in difficult circumstances, but of an editorial attitude that assumes that more science will not help newspaper sales, or more probably even that the result of more science will be a decline in readership. The surveys on public attitudes to science we have summarized in chapter three, the large audiences of television programmes such as *Tomorrow's World* and *QED*, which far exceed the readership of any national daily newspapers, and the apparent appeal of scientific features in some daily and Sunday newspapers demonstrate that this negative editorial attitude to science is unwarranted. With one notable exception, our approach, as a group, to newspaper editors evoked no response, in marked constrast to the positive interest and response we elicited from many other sections of society. **We urge newspaper editors and their senior staff to take a much more positive attitude to the role of science in their newspapers, to encourage their science, technology and health correspondents to produce more material and to enable it to get space in the newspapers, and to encourage their journalists, in general, to consider the scientific connotations of their stories.**

5.9. There is an increasing and welcome trend for feature articles in newspapers on issues, especially computing, business and health, that have an intrinsic scientific content. As already argued in paragraph 5.6, features provide more scope and fewer constraints on the presentation of science in general, and also enable more participation from the scientists themselves. **We favour, therefore, a continuing increase in the number and scope of scientific or science-related feature articles.**

5.10. The range and quality of science features and news programmes on radio and television is generally very high. As already emphasized, some of these programmes have very large audiences, while others, such as *Science Now* and *Medicine Now* on radio, cater effectively for smaller, more specialized audiences. Both types of programmes can play a valuable role in furthering the public understanding of science. The number and quality of such programmes should be sustained, and if anything increased. **We urge the Peacock Committee, in its review of BBC funding and policies, to take into account the importance of the BBC science output.**

5.11. Television and radio programmes directed at particular themes can have a major influence. A most notable example was the *Horizon* programme 'When The Chips Are Down' and the subsequent computer literacy projects, including the promotion of the BBC microcomputer. These have played a major role in enhancing computer awareness in this country, resulting in one of the largest ratios of computers per person in any country. There have also been effective health promotion programmes, for example against cigarette smoking and on cancer prevention. **There is a strong case for similar series of programmes to promote, for example, understanding of technology, commerce and industry, statistics, and science in general.**

5.12. Science drama series, such as those on Darwin, Oppenheimer, the Curies and Louis Pasteur, are an attractive and entertaining way to portray science, its historical development and especially its human aspects. **More consideration should be given by the media as to how to present science and scientific development as a human activity using biographical and dramatic approaches.**

5.13. Television can be an especially powerful influence on the attitudes of children. The portrayal of science on programmes such as *Blue Peter* or *Saturday Superstore*, special children's science programmes such as the *Great Egg Race* or the Royal Institution Christmas Lectures (also watched by many adults) and the schools broadcasts science programmes can play a very important role in shaping the future attitudes of children to science. **It is important, therefore, that the scope and quality of science broadcasting for children be sustained.**

5.14. Popular scientific and technical magazines such as *New Scientist* and *Practical Electronics* are important sources of scientific information and education for the scientifically attentive public. The British public, however, supports a much smaller number of such magazines than do, for example, the French or North Americans. These magazines can act as a valuable intermediary between the scientific community and the general, non-scientific press, with the latter basing stories on articles appearing in them. Hobby magazines, especially in the computing and electronics area, also play a significant role as a source of certain types of scientific information. There are, in addition, from time to time scientifically based articles in general magazines, especially for example in health-related areas in women's magazines, as well as regular features in journals such as *The Economist*. In all these cases it is important for the journalists to have good contacts with a sympathetic scientific community.

5.15. Popular scientific books, such as those accompanying some of the major television series, are another important source of scientific information for the general public. In addition, as for the broadcast media, science appears in other forms, notably in science fiction. Unfortunately, some popular books, for example on diet or alternative medicine, even from large and well-known publishers with a respectable scientific output, are grossly inaccurate or even positively misleading. Similarly, some science fiction can grossly distort scientific possibilities and create much concern in a public with limited scientific literacy and so limited ability, as mentioned in paragraph 2.8, to sort the plausible from the implausible or rank impossible. Formal mechanisms for vetting the quality of such popular material would be tantamount to censorship and so unacceptable. But responsible and publically intelligible comment from the scientific community should help to ensure that the extremes of distortion are at least to some extent curbed by the major publishers and film producers. **Scientists and science journalists should be positively encouraged to produce accurate and appealing popular science books for the general public.**

6. THE SCIENTIFIC COMMUNITY

6.1. **Scientists must learn to communicate better with all segments of the public, especially the media.** Two recurring themes of the previous chapter on the media were, on the one hand, the scientist's mistrust, lack of understanding and often unwillingness and inability to communicate adequately with the journalist, and on the other hand the importance of a good rapport between scientist and journalist if science is to be properly and adequately represented in the media. This same good rapport is also needed with Parliament, the Civil Service and industry. Our group, though certainly not exclusively scientific, was a product of the scientific community, and so it is appropriate that **our most direct and urgent message is for the scientists—learn to communicate with the public, be willing to do so, indeed consider it your duty to do so**. This chapter considers the problems of such communication and various suggestions for their solution.

6.2. Professional scientists have mostly delegated to others the task of communicating science to the public. Nevertheless, some outstanding research scientists have also been outstanding popularizers. T.H. Huxley and John Tyndall, Arthur Eddington and James Jeans reached large lay audiences with their accounts of developments in science, and men like J.D. Bernal, Lancelot Hogben, J.B.S. Haldane and Jacob Bronowski put over the social and cultural aspects of science. But these people were unusual, and their activities were by no means always properly appreciated by the scientific community. Indeed, within the scientific community there is still often a stigma associated with being involved with the media. There is now, however, a substantial body of professional journalists and writers (The Association of British Science Writers, for example, has over 200 members) whose job it is to interpret science and scientists to the lay public. It is tempting, therefore, for professional scientists to conclude that the business of communicating with the lay public may safely be left to others. After all, scientific research is what scientists are good at, what they are paid to do and what should have first claim on their attention. Communicating science to the lay public is not easy and, it may be thought, should be left to those whose full-time job it is.

6.3. Such an attitude is no longer appropriate, and probably never was. The scientific community is necessarily the ultimate source of scientific understanding. Given the importance of public understanding of science, as discussed in chapter two, scientists as a whole must recognize that they have a serious responsibility to speak to the lay public. Scientists are also democratically accountable to those who support scientific training and research through public taxation. If the public is not told about the scientific research it supports, it is unlikely to worry if the level of support is reduced. **It is clearly a part of each scientist's professional responsibility to promote the public understanding of science.**

6.4. The first requirement is to learn how to communicate science effectively to a lay public. Some aspects of this can and should be taught formally to all professional scientists. The language used must be simple and free of jargon, without being condescending. Everyday analogies can be very helpful in explaining complicated scientific concepts. Fluent communication of science to the lay person, however, ultimately depends on experience. Opportunities should therefore be provided throughout all formal education for gaining such experience. A useful step in this direction would be, as suggested by others, for **every Ph.D. candidate to explain the essential background and nature of his or her thesis work to a lay audience, for example in the form of a short written article.**

6.5. Succinct communication is needed, not only by the media, but also by busy politicians and company executives. A few minutes or three pages of A4 typescript is often the maximum time or space available for explaining even the most complex scientific issue. A normal scientific training points in the opposite direction, namely toward a carefully considered and much qualified statement. Clear and succinct verbal communication must be specifically learnt and practised.

6.6. **Scientists must learn about the media and their constraints, as discussed in the previous chapter, if they are to put over scientific issues effectively and without distortion.** There are very good books for the scientist about the media and how to approach them (for example Barbara Gastel, *Presenting science to the public* (ISI Press, 1983) or University of Birmingham Information Office, *Can I quote you on that?* (1983)), and these can be supplemented by lectures and by direct contact with journalists, as well as broadcasts and visits to newspapers.

6.7. The scientific community is divided into many sectors, not only by subject but also by institutions, such as learned societies, professional bodies, research institutes, universities and their departments, research councils, central and local government departments, private foundations and charities, and industrial and commercial organizations. Public understanding of science is already a central activity of organizations like the British Association for the Advancement of Science, the Royal Institution and the Royal Society of Arts, which are explicitly constituted in part for this purpose, and many learned and professional bodies are also aware of their responsibilities in this area. **Each sector should however assess its potential for improving public understanding of science on a broad front, for example by providing training on communication and about the media, arranging lectures, demonstrations and scientific competitions, providing briefings for journalists, politicians and others, and generally improving their public relations**. Some examples of these approaches are discussed in the following paragraphs.

6.8. The Royal Society, in an initial response to the importance of public understanding of science and following the setting up of this Committee, has started a series of lectures on key scientific topics aimed specifically at lay audiences. All the Society's lectures and discussions are already open to the general public, but are mostly directed at specialist science audiences. **To emphasize further the value it attaches to good communication of science to the public we suggest that the Society institute an annual prize and lecture for the individual scientist or scientific organization that has done most to promote public understanding of science.**

6.9. During the course of, and as a result of, this study the Royal Society has begun to provide briefings for science writers and broadcasters in connection with its discussion meetings. This is already the practice of some learned scientific societies, and **we recommend that all societies consider whether their meetings offer opportunities for briefing journalists on important developments in science.**

6.10. **We recommend that the Royal Society also organize press seminars to brief journalists on the scientific background to foreseen, and unforeseen, developments in current affairs**. Examples where such 'briefing seminars' might have improved the quality of coverage are the sinking of the *Mount Louis* (where ignorance of the properties of uranium hexafluoride led to confused reporting), the publication of the Warnock Report on human fertilization and embryology (where the scientific background to the Report's recommendations was little understood) and Parliamentary debates on issues that have a considerable scientific content. The purpose of such briefing seminars would be to provide factual information about the technical aspects of the issue concerned. It would be important to avoid the impression of lobbying for a particular view of how the issue should be resolved. The Society would need to establish a mechanism for identifying issues on which a briefing was desirable and for organizing the briefing seminar in the shortest possible time, preferably within 24 hours of an unexpected event or in advance of an expected event. Consideration should be given to ways of making these briefing seminars accessible for journalists not living within easy travelling distance of London, e.g. by providing succinct written briefings.

6.11. Other mechanisms for improving the provision of appropriate scientific information to jounalists, as we discussed with the Association of British Science Writers, could include **a journalist's information and research service provided by the Society, and regular written briefings providing authoritative factual information on the scientific aspects of important issues. These might often best be prepared by a more specialist learned society, though the Royal Society could serve the role of a central information network for the production of such briefings**. The *Earthscan* publications, produced by the International Institute for Environment and Development with financial support from, among others, the World Bank and the United Nations Environment Programme, provide a model here. The Council for Science and Society and the British Association for the Advancement of Science also periodically publish reports dealing with the social aspects of science such as *in vitro* fertilization, advanced technology in medicine and the problems of an ageing population. As already mentioned in paragraph 3.19, some government reports in addition provide valuable background information on key scientific issues.

6.12. In the USA the Scientists' Institute for Scientific Information has established a Media Resource Service, which has contacts with 15 000 experts in defined fields who are available at any time to deal with press queries on scientific issues. Launched in 1977, it now handles some 200 queries per month. In the UK the Ciba Foundation is planning to provide an analogous service from October 1985, covering medicine, biological science, chemistry, physics, astronomy and space, Earth science, energy, computer science and the environment. The service will be available free of charge to all media outlets. We welcome this initiative and hope that it will be used not only by specialist science journalists but also, indeed more especially, by nonspecialists. The general journalists may often have to report events or issues with a scientific element, but have few contacts in the scientific community. If it proves successful we hope it will be extended by the Ciba Foundation or by other organizations to cover the full range of science.

6.13. Parliamentarians can be influenced either indirectly through their constituents, or directly. As charitable organizations, learned scientific societies are limited in the extent to which they are free to lobby, but they can certainly provide factual information to Parliamentarians on the scientific aspects of issues of current public concern. The Royal Society of Chemistry's Parliamentary Link Scheme, through which some 30 MPs have established connections with professional members of the RSC living in their constituencies, is a good example of the possibilities. Close links with senior civil servants, including Departmental Chief Scientists, are also important. **The scientific community as a whole needs to develop mechanisms for ensuring that Parliamentarians are aware of scientific information relevant to issues of public policy**.

6.14. The Parliamentary and Scientific Committee, which brings Parliamentarians together with senior members of a wide range of scientific and industrial organizations, has considerable potential as a forum for improving the understanding of science in one very important sector of the lay public. It faces a familiar difficulty, however, in that very few Parliamentarians who are not already interested in science attend its meetings. Although the Committee provides useful opportunities for informed debate, it does not yet achieve the broader aim of persuading a wide range of Parliamentarians that they should pay more heed to science. One possibility would be for the Committee to organize meetings, at short notice if necessary, to discuss the scientific aspects of issues about to be debated in Parliament so that Members can be more fully briefed. Such meetings might attract larger numbers of Parliamentarians than meetings of more long-term interest but less immediate relevance. The Royal Society could act as a catalyst for such briefings along similar lines to its proposed role for journalists.

6.15. Communication with the mass media and the wider public is, as already emphasized in paragraph 6.7, the responsibility of all sectors of the scientific community. An important mechanism for facilitating communication is to have a well-defined point of contact for accepting media and general public enquiries, namely to have a good public relations organization. This should, for example, guide members of a scientific institution to recognize what might be of interest to the media, help and train them to convey their ideas in appropriate language, and encourage visits by and maintain contacts with the media and other appropriate individuals and organizations. The establishment of the Standing Committee of University Information Officers is a welcome step in this direction. Different institutions may have varying constraints on their public relations activities according, for example, to whether they are government or industrial organizations, or charities. **We strongly recommend, however, that all scientific organizations and institutions develop good public relations procedures, and that the Royal Society ensures the availability of appropriate advice.**

6.16. The Royal Society, as the foremost learned scientific society in the country, clearly has a major and central role to play in promoting the public understanding of science, and many possibilities for it to do so have been suggested in the preceding paragraph. The setting up of this *ad hoc* Group reflects the importance the Society attaches to this issue. **We now recommend that the Society establish a standing committee for the public understanding of science. Its responsibilities would be** *(a)* to monitor and review progress in the public understanding of science and its impact on society as a whole; *(b)* to ensure the provision of advice and guidance to scientific institutions and organizations on how to promote public understanding of science, for example, on communication of science, on the media, on other activities and on public relations in general; *(c)* to oversee the Society's own activities such as lectures to the lay public, prizes for communication, journalists' seminars, briefings and press conferences, and contact with the Parliamentary and Scientific Committee and other similar bodies.

7. PUBLIC LECTURES, CHILDREN'S ACTIVITIES, MUSEUMS AND LIBRARIES

7.1. There is, as already mentioned, considerable scope for learned societies to provide public lectures both on scientific developments and on the social and industrial aspects of science. These lectures can be aimed at the general adult public and at schoolchildren of various ages. The range of materials, audiences and styles is very wide. The Royal Institution's Christmas Lectures, given to live audiences mainly in their early teens, actually reach a very diverse audience through television broadcast and thus generate a good deal of public interest. The Royal Institution's master classes provide a model for stimulating the interest of bright children in mathematics and science. Popular lectures can form part of regular activities, as with the British Association Young Scientists, or of periodic events such as the annual meeting of the British Association. Locally organized 'science weeks', such as the very successful biennial event in Cardiff, provide extensive opportunities for popular lecturing. **Scientific societies should encourage their members to contribute to such activities and should where possible launch their own programmes.** Societies that have regional branches are particularly well placed to contribute to local initiatives.

7.2. There are numerous ways of engaging children's interest in science in addition to the stimulus they receive through their formal education. The Royal Society, for example, has since 1957 supported scientific research carried out by school teachers with the involvement of their pupils. With the help of industrial sponsorship and a total budget of only a few thousand pounds, the Society is able to support some 35 research projects in schools at any one time and to ensure that the project teams have the benefit of expert advice from professional research scientists in the appropriate discipline. Good projects have been demonstrably successful in arousing children's interest and in increasing their understanding of the nature of scientific research. Another imaginative scheme is the British Association's Awards for Young Investigators, in which groups of 8- to 12-year-olds can win various awards for successfully undertaking scientific investigations and projects. This has proved extremely popular, not only in primary schools but also in youth clubs and similar organizations. The scheme is supported by grants from the Departments of Trade and Industry and of Education and Science and will, we hope, be extended to older age groups.

7.3. **Imaginative competitions can also stir up children's interests.** A good example is the competition organized by the Royal Society of Chemistry, with British Oxygen Company sponsorship, to mark the 250th anniversary of the birth of Joseph Priestley, in which schools were asked to compile a four-page tabloid newspaper as if from Priestley's time, including both scientific and other material. Another rather different example is the ITN–Space Services International competition in which school teams were asked to design an experiment to be flown on the Space Shuttle. Over 100 schools took part, and the winning experiment is expected to be flown in late 1985. One of the values of these sorts of competition is that they involve a variety of skills and knowledge, and thus help to show the relation of science to other activities. Scientific societies could, as some already do, organize regular essay competitions, for example, in relation to anniversaries of major events or to scientific issues of public concern, as a way of stimulating thought about public aspects of science. Scientific societies with local branches should stimulate interest in the scientific aspects of, for example, the local natural environment, local industry and local development. Such activities can sometimes have greater impact than ones organized nationally.

7.4. There are many opportunities for voluntary, non-vocational adult education in this country. For example, the Workers' Educational Association, Local Authority evening schools and university extramural departments provide a wide range of classes, which attract considerable numbers of adults to study a variety of subjects. These tend to be organized differently from the formal education system, and some of them offer scope for introducing motivated adults to the non-technical aspects of science. They can contribute very usefully to improving public understanding of science. **We recommend that those responsible for organizing adult education provide a larger number of courses dealing with general aspects of science.**

7.5. **Museums are a major informal mechanism for effecting public understanding of science.** They vary widely in content, from small museums of local technology to metropolitan museums dealing with most of basic and applied science. They have a variety of functions, including preservation of objects, promotion of historical and cultural research, promotion of modern scientific research (for example at the Natural History Museum), promulgation of local or national cultural identity, education and entertainment. In recent years the educational function has received a more explicit emphasis and a number of multi-media displays have been designed to engage visitors' interests and illustrate basic scientific principles. At the same time a rapid growth in the number and popularity of working industrial sites has allowed many people to see historical technological processes in action. The best museums reach very high standards in promoting better public understanding and, as already mentioned in paragraph 3.23, in some cases reach a very large public.

7.6. There are two very promising developments in the museum world. One is the approach, pioneered in the San Francisco Exploratorium and the Ontario Science Centre, and being taken up in this country by the London Science Museum's 'Launch Pad' scheme and the Bristol 'Exploratory', that adds a new dimension to the concept of interactive displays. This approach involves the development of exhibits that visitors can experiment with directly (rather than merely activate) and that provide an opportunity to explore scientific principles and their applications. This is a long way from the traditional concept of a museum, and is complementary to the usual roles of a museum rather than a substitute for them. It is an initiative we would encourage. **We welcome the establishment, by one of the Sainsbury Family Charitable Trusts, of a 'priming' fund to help in developing a network of interactive technology centres throughout the UK, supplementing the pioneer ventures in London and Bristol.**

7.7. Another related development is one currently planned for the Parc de la Villette in Paris. Here a small area will be set aside for exhibits explaining the scientific principles behind some issue of current public concern. Each exhibit will be shown for one month only, so as to maintain topicality. These exhibits are a sort of three-dimensional equivalent of a feature article in a monthly magazine or a journalists' briefing seminar. Museums in this country should consider such schemes as a contribution to more scientifically informed discussion about public issues.

7.8. Public libraries, mostly local, as a source of books and magazines on scientific issues also make a valuable contribution to public understanding. They can, moreover, complement and supplement school libraries, in the same way that museums interact with and complement other school activities. **Resources for local libraries, and especially their scientific content, need to be sustained and encouraged.**

8. INDUSTRY

8.1. The importance of public understanding of science for industry, and some of the contributions that industry itself can make, have been mentioned throughout this report. A prime consideration is the need for appropriate scientific understanding at all levels from the shopfloor to the boardroom. The extension of science education and the overall broadening of education called for in chapter four will benefit industry at all these levels, but more especially in higher management. **Industry must contribute to the current debate on science education so that its future needs are adequately catered for.**

8.2. More immediate action is, however, called for. **In-service training should help to improve the overall level of appropriate scientific knowledge.** It needs to impart a broad understanding of the principles behind a company's technology, the limits and uncertainties of the science and technology, and their social significance, rather than simply to transfer sufficient knowledge to enable staff to operate existing machinery. This applies to all levels of staff from senior manager to operative, though obviously tailored to suit their different needs. If a firm's own employees have some understanding of what underlies its operation, they are also able to stimulate better informed discussion about that firm in its own neighbourhood. Although many companies have recognized this and acted on it, many others still do not realize the importance and value of in-service training. The use of the public and university teaching sectors for in-service training wherever possible could be mutually beneficial.

8.3. The status of scientific research personnel in industry can be improved in a variety of ways, most obviously by bringing their salaries and promotional prospects more in line with those in other functions such as accountancy and marketing. **The larger science-based companies should be encouraged to require their middle management to have appropriate professional institute membership based on a formal scientific qualification coupled with a period of organized training on the job.** This would set a premium on the need for scientific skills at the middle management level, which could be expected to spread from the larger to the smaller companies.

8.4. **Scientists involved in research in industry should be encouraged to take wider and earlier opportunities in management positions, helped by appropriate management training.** This should eventually provide a larger source of scientifically trained people for top management positions. **Consideration should also be given to bringing more scientists, with appropriate experience, from academic institutions directly into top management, or as non-executive company directors.**

8.5. **More opportunities should be provided for exchanges between schools and industry, as discussed in paragraphs 4.10, 4.12 and 4.13.** This exchange both helps schools to learn about industry and industry to contribute to appropriate science education in schools.

8.6. The need for scientists to communicate with the media and the general public, as discussed in chapters five and six, is as great in industry as elsewhere. **Industry, furthermore, often has the resources to promote activities such as lectures, competitions and seminar briefings or to sponsor science programmes on the media. This support should be encouraged, because it is likely to provide the best hope for adequate resources for improving the public understanding of science, which should benefit industry as much as it does other sectors of society.**

8.7. **Industry, learned societies and other scientific institutions should cooperate in promoting activities aimed at improving public understanding of science.** Such cooperation would improve not only the actual implementation of the initiatives but also the mutual understanding of the parties involved, which should help them to present a more rounded view of science. Some industrial firms make considerable efforts to explain what science is, for example through advertisements that are genuinely informative about the nature and outcome of scientific research, through films, publications and exhibitions. There is scope for closer cooperation between learned scientific societies and industry in promoting such activities.

8.8. Firms have a major task in educating the public about the scientific and technological bases of their activities. It is neither possible nor desirable for them to try to circumvent public opinion by ignoring it—rumours and half-truths are likely to circulate and are bound to misinform. **At both the national and, particularly, the local level, firms should take all reasonable steps to ensure that the public can understand both the benefits and the problems of what they are doing.** This includes providing the public with sufficient scientific and technological background information to help them balance the benefits and problems of different options. For example, freely available attractive and intelligible publications, informative advertisements and open days, can all contribute to this. Such a policy requires a willingness to be open, for example, about risks, the skill to communicate at the right level and imagination in finding ways of putting information across. A more open policy of this sort is in the long-term interests of both industry and the public. Many firms do of course already make considerable efforts in this direction, but there is much more that could be done. It is a question not of selling industry but of improving public understanding of the scientific and technological (and other) aspects of policy issues affecting industry.

9. CONCLUSIONS AND RECOMMENDATIONS

General

9.1. Science and technology permeate our daily lives. Our industry and national prosperity depend on science, we use devices created by science and technology at home and at work, and many personal and public decisions have a major scientific aspect. At both national and individual levels science and technology make key contributions to our survival in an increasingly competitive environment. In addition, the major findings of science, for example about cosmology or evolution, profoundly influence the way we think about ourselves and are an important part of our culture.

9.2. For all these reasons an understanding of science is important:

(i) for private individuals, for their personal satisfaction and wellbeing;

(ii) for individual citizens, to participate in a democratic society;

(iii) for skilled and semi-skilled workers, a large majority of whose occupations now have some scientific involvement;

(iv) for people employed in the middle ranks of management and in professional or trade union associations, to help their decision-making in a scientific environment;

(v) for those responsible for major decision-making in our society, particularly in industry and government, where few, if any, issues do not have a scientific or technical aspect.

9.3. Understanding the nature of risks and uncertainty is an important part of the scientific understanding needed both for many public policy issues and for everyday issues in our personal lives. [2.10]

9.4. Able scientists mostly wish to pursue scientific research and as a result tend to shun the higher administrative responsibilities of government, the Civil Service and industry. For this and other reasons there are comparatively few people even with a primary training in science in the upper levels of government, the Civil Service and industry. To ensure that those who do achieve such positions of influence without a primarily scientific education, have at least some understanding of science, scientific education must be extended and in particular broadened at all levels. [2.12]

Present position

9.5. There are many surveys of *attitudes* to science and technology, but, outside the formal educational system, few are devoted to assessing the *understanding* of science and technology. **We recommend that the Economic and Social Research Council and other appropriate bodies sponsor research into ways of measuring public understanding of science and technology, and of assessing the effects of an improved understanding. We also recommend that the sources from which individuals obtain their information be actively investigated.** [3.1]

9.6. Adequate levels of literacy and numeracy are minimal requirements for an acceptable level of public understanding of science. A survey has shown that in the UK as a whole some 2–3 million adults cannot read properly, while some 1–1.5 million adults find difficulty in doing simple arithmetic. Renewed efforts to improve adult literacy and numeracy must be an essential element in improving public understanding of science, as indeed they are for most other aspects of modern life. [3.2]

9.7. Surveys of public attitudes to science show that the public has a considerable interest in science and would like to know more about it, while being wary of some of its applications. The interest in science is emphasized by the large audiences for television programmes such as *Tomorrow's World* and *QED* and by the large number of visitors to the Science and Natural History museums. Public attitudes to science are a valuable guide to the improvement of understanding. **We recommend, therefore, that the Economic and Social Research Council and other appropriate bodies devise methods of monitoring attitudes to science in the United Kingdom along the lines of the USA National Science Board's *Science indicators*.** [3.4–3.15]

9.8. Government reports such as the 1975 Ashby Report on genetic manipulation, the Warnock Report on *in vitro* fertilization and reports from the House of Lords Select Committee on Science and Technology, make a substantial contribution to public understanding and debate of scientific issues. **We recommend that popular versions of such reports be made widely available as a matter of course.** [3.19]

Formal education

9.9. A proper science education for all must be the starting point for any attempt to achieve an adequate level of public understanding of science. Many reports, including one from the Royal Society in December 1981 that led to the production of this Report, have come to a consensus on the need for a balanced education in science for all to the age of 16. This should be based on a broad curriculum with an emphasis on principles as well as facts and on the practical and social implications of science. There is also a need for better resources for science teaching, for in-service training and for improved schools-industry contact. Though the benefits of such recommended reforms may be seen only in the comparatively long term, this in no way diminishes the urgency with which they should be implemented. [4.1, 4.2, 4.5]

9.10. All pupils should follow a broad course of science and technology up to the age of 16. The teaching should impart familiarity with the scientific method, its nature and limitations, and the social roles of science and technology, as well as with scientific facts. Practical problem solving and the relevance of science to technology should be emphasized. Mathematical education should aim to bring about confidence in numeracy and, while based on practical and relevant examples, experience in the use of symbols. [4.4]

9.11. Some understanding of statistics, including the ideas of risk, uncertainty, ratios and variability, which are intrinsic to the scientific method and are a major factor in understanding many personal and public issues, should be a goal of all science courses. **We recommend that consideration be given to the development of new materials for the teaching of statistics in a practical and relevant way to all pupils up to the age of 16.** [4.4]

9.12. The teaching of non-scientific subjects, such as English and history, should include examples from science and technology. [4.6]

9.13. The primary level is where an excellent foundation can be laid for future understanding of science. Many primary teachers, however, are inadequately qualified in science. All primary teachers should have some basic training in science and mathematics. Furthermore, **we recommend that much greater priority be given to laying the foundations for a sound understanding of science through appropriate science courses in all primary schools.** [4.7]

9.14. Good science teaching depends critically on an adequate supply of good and dedicated teachers. The relatively poor salaries of science teachers as compared to scientists elsewhere, especially in industry, are a major barrier to recruitment. **The status and salary of teachers must be improved so that a larger proportion of teachers with the insight and ability to impart the excitement of science can be attracted into the profession.** Knowledge of new scientific discoveries and implementation of new curricula requires periodic updating. **Attendance at in-service courses should, therefore, form an integral part of a teacher's activities.** [4.9, 4.11]

9.15. Science and mathematics must be seen by pupils to be useful bases for future life and future employment. For this, an appreciation of industry and commerce is essential. This can be achieved through courses on science in a social context, such as the SISCON project, as well as by other activities such as the British Association Young Scientists, the Standing Conference on Schools, Science and Technology and the Science and Technology Regional Organizations. Exchanges between schools and industry can be very important in developing a broader appreciation of the role of science and technology in industry. **We recommend that industry and schools extend the range of opportunities for exchange—teachers into industry and industrialists into schools, and pupils' visits to factories and laboratories—to broaden the contacts between school and industry and increase the technological and industrial relevance of the science taught in schools.** [4.10, 4.12, 4.13]

9.16. Education in this country for pupils over the age of 16, especially in the sixth form, is appallingly narrow. **No pupil at school should be allowed to take only arts, or only science subjects, even after the age of 16.** A revised system allowing a broader range of subjects to be taken at a somewhat lower level than A-level is urgently needed. University teachers, especially of science subjects, must be persuaded of the overall value to our society of a broader post-16 educational system. **We also urge universities to introduce general studies, or find some other way for undergraduates to benefit from the proximity in the same institution of experts in subjects outside their own courses of study.** [4.14, 4.16, 4.17]

9.17. The progress of science is such that education at school and even university cannot suffice for a lifetime. **We recommend, therefore, that new approaches to continuing and further science education should be developed.** [4.19]

9.18. **To achieve the goals set out here for an appropriate science education for all, extra resources must be made available.** This must surely be one of the best possible investments for our future prosperity and wellbeing. [4.15]

Mass media

9.19. The mass media are a powerful influence on public understanding of science. The scientific community and the media work in very different ways and are, on the whole, often ignorant of each others' procedures and constraints. These attitudes need to be changed. If scientists are to communicate with the public through the media they must learn to accept the media's constraints and to convey information on the journalists' terms. The journalists, on the other hand, who may not themselves be scientists, have to understand the attitude of the scientists. [5.1–5.5]

9.20. Science appears in many broadcast programmes or newspaper articles that are not specifically identified as science items. **There is a strong case for including more science in such general programmes. Mechanisms therefore need to be found for improving the contact with scientists and the understanding of science, not only by science journalists but also, and perhaps even more importantly, by journalists as a whole.** [5.7]

9.21. Science is, in general, much less well represented in newspapers in this country than it is on the broadcast media. Surveys on public attitudes to science, however, as well as the large audiences for television programmes such as *Tomorrow's World* and *QED*, show that a negative editorial attitude to science is unwarranted. **We urge newspaper editors and their senior staff to take a much more positive attitude to the role of science in their newspapers, to encourage their science, technology and health correspondents to produce more material and to enable it to get space in the newspapers, and to encourage their journalists in general to consider the scientific connotations of their stories.** [5.8]

9.22. Feature articles allow more time for the journalist to assimilate the scientific background and more space in which to put over a story. They also offer the opportunity for scientists themselves to be involved in, or contribute to, features. **We favour, therefore, a continuing increase in the number and scope of scientific or science-related feature articles in daily and Sunday papers and in magazines.** [5.6, 5.9]

9.23. The range and quality of science features and news programmes on radio and television is generally very high. Programmes directed at particular themes can have an especially important influence. **There is, therefore, a strong case for series of programmes to promote, for example, understanding of technology, industry, statistics and science in general.** [5.11]

9.24. Science drama series are an attractive and entertaining way to portray science and its historical development. **More consideration should be given by the media as to how to present science and scientific development as a human activity using biographical and dramatic approaches.** [5.12]

9.25. Television can be an especially powerful influence on the attitudes of children. **The scope and quality of science broadcasting for children should, therefore, be sustained.** [5.13]

9.26. Given the importance of science programmes on radio and television **we urge the Peacock Committee in its review of BBC funding and policies to take into account the importance of the BBC science output.** [5.10]

9.27. Popular scientific books are an important source of scientific information for the general public. Unfortunately, however, they are sometimes grossly inaccurate, or even deliberately misleading. **Scientists and science journalists should be positively encouraged to produce accurate and popular science books for the general public.** [5.15]

Public lectures, museums and other activities

9.28. There is considerable scope for learned scientific societies to provide public lectures for adults and children, both on scientific developments and on the social and industrial aspects of science. Other activities include, for example science weeks and master classes for children. Scientific societies should encourage their members to contribute to such activities and consider launching their own programmes. [7.1]

9.29. There are many ways of engaging children's interest in science, for example through research schemes, young investigator awards and a variety of competitions. **Such activities should be encouraged both by industry and scientific societies, especially where they can generate interest in local scientific affairs.** [7.2, 7.3]

9.30. There are many opportunities for voluntary, non-vocational courses in this country. **We recommend that those responsible for organizing adult education provide a larger number of such courses, dealing with general aspects of science.** [7.4]

9.31. Museums are a major informal mechanism for effecting public understanding of science. New developments involving interactive exhibits and temporary exhibits on the scientific aspects of current affairs are of great interest. We welcome the establishment of a priming fund to help in developing a network of interactive technology centres throughout the United Kingdom, supplementing the pioneering exploratory ventures in London and Bristol. [7.5–7.7]

9.32. Public libraries, by making available scientific books and magazines, also make a valuable contribution to public understanding of science. **Resources for local libraries, and especially their scientific content, need to be sustained and encouraged.** [7.8]

Industry

9.33. Scientific understanding is needed in industry at all levels from the shop floor to the boardroom. **Industry must therefore contribute to the current debate on science education so that its future needs are adequately catered for.** [8.1]

9.34. For a more immediate improvement of scientific understanding, **in-service training is needed to improve the overall level of appropriate scientific knowledge.** [8.2]

9.35. **The larger science-based companies should be encouraged to require their middle management to have appropriate professional institute membership based on a formal scientific qualification,** coupled with a period of organized training on the job. This should contribute to improving the status of scientific research personnel in industry. [8.3]

9.36. **Scientists involved in research in industry should be encouraged to take wider and earlier opportunities in management positions, helped by appropriate management training. Consideration should also be given to bringing more scientists from academic institutions with appropriate experience directly into top management, or as non-executive company directors.** [8.4]

9.37. Industry has the resources to promote activities such as lectures, competitions and seminar briefings, or to sponsor science programmes on the media. **Such support should be encouraged,** as it may well provide the best means for making available adequate resources for improving public understanding of science, which should benefit industry as much as it does other sectors of society. [8.6]

9.38. **Industry, learned societies and other scientific institutions should cooperate in promoting activities aimed at improving public understanding of science.** [8.7]

9.39. Firms have a major task in educating the public about the scientific and technological bases of their activities. **At both the national and particularly the local level, therefore, firms should take all reasonable steps to ensure that the public can understand both the benefits and the problems of what they are doing.** [8.8]

The scientific community

9.40. Scientists must learn to communicate better with all segments of the public, especially the media. Only in this way can the rapport between scientists and journalists be improved, as it also should be with Parliament, the Civil Service and industry. [6.1]

9.41. In the past, professional scientists have mostly delegated to others the task of communicating science to the public. Within the scientific community there is still often a stigma associated with being involved in the media. Such attitudes are not appropriate. Given the importance of public understanding of science and the extent to which scientists must be democratically accountable to those who support their training and research through public taxation, **it is clearly a part of each scientist's professional responsibility to promote the public understanding of science.** [6.2, 6.3]

9.42. Communicating science effectively to the public can and should be taught formally to all professional scientists. **Opportunities should be provided throughout the formal education period for gaining experience in explaining science simply, without jargon and without being condescending. Every Ph.D. candidate, for example, should explain the essential background and nature of his or her thesis work to a lay audience in the form of a short written article or lecture.** [6.4–6.6]

9.43. **Scientists must learn about the media and their constraints if they are to put over scientific issues effectively and without distortion.** [6.6]

9.44. The scientific community is divided into many sectors including institutions, learned societies, professional research institutes, universities and their departments, research councils, central and local government departments, private foundations and charities, and industrial and commercial organizations. **Each of these sectors should assess its potential for improving public understanding of science on a broad front, for example by providing training on communication and about the media, arranging lectures, demonstrations and scientific competitions, providing briefings for journalists, politicians and others and generally by improving their public relations.** [6.7]

9.45. There is a variety of mechanisms for improving the provision of appropriate scientific information to journalists, including press seminars and briefings. In the USA the Scientist's Institute for Scientific Information has established a media resource service, which has contacts with 15 000 experts in defined fields who are available at any time to deal with press queries on scientific issues. The Ciba Foundation in the United Kingdom is planning to provide an analogous service from October 1985. This is an initiative that we welcome and hope will be extended to cover a broad range of scientific areas. [6.12]

9.46. Parliamentarians need to be kept abreast of scientific issues. **The scientific community as a whole, therefore, needs to develop mechanisms for ensuring that Parliamentarians are aware of scientific information relevant to issues of public policy**. [6.13]

9.47. An important mechanism for facilitating communication is to have a good public relations organization. **We strongly recommend that all scientific organizations and institutions develop good public relations procedures.** [6.15]

The Royal Society

9.48. The Royal Society, as the foremost learned scientific society in the country, clearly has a major and central role to play in promoting the public understanding of science. To this end there is a variety of mechanisms and activities that it should promote.

9.49. **We suggest that the Society institute an annual prize and lecture for the individual scientist or scientific organization that has done most to promote public understanding of science.** [6.8]

9.50. Briefings for science writers and broadcasters in connection with Royal Society Discussion Meetings have been implemented during the course of this study. This practice should be continued and **all societies should consider whether their meetings offer opportunities for briefing journalists on important developments in science.** [6.9]

9.51. **We recommend that the Royal Society organize press seminars to brief journalists on the scientific background to foreseen and unforeseen developments in current affairs.** Another mechanism for improving information to journalists would be to **institute a journalists' information and research service through the Society, which would make available regular written briefings providing authoritative factual information on the scientific aspects of important issues.** These might often best be prepared by a more specialist learned society, and then **the Royal Society could serve the role of a central information network for the production of such briefings.** [6.10, 6.11]

9.52. The Parliamentary and Scientific Committee, which brings Parliamentarians together with senior members of a wide range of scientific and industrial organizations, has considerable potential as a forum for improving the understanding of science in this very important sector of the public. **The Committee should be urged to organize meetings at short notice, if necessary, to discuss the scientific aspects of issues about to be debated in Parliament, so that members can be more fully briefed. The Royal Society could act as a catalyst for such briefings** along similar lines to its proposed role for journalists. [6.13, 6.14]

9.53. To implement this wide variety of activities devoted to the public understanding of science, **we recommend that the Society establish a standing committee for the public understanding of science.** Its responsibilities would be: (a) to monitor and review progress in public understanding of science and its impact on society as a whole; *(b)* to ensure the provision of advice and guidance to scientific institutions and organizations on how to promote public understanding of science, for example on communication of science, on the media, on other activities and on public relations in general; *(c)* to oversee the Society's own activities such as lectures to the lay public, prizes for communication, journalists' seminars, briefings and press conferences and contact with the Parliamentary and Scientific Committee and other similar bodies. [6.16]

9.54. The mechanisms for improving public understanding of science are varied and, in some cases such as in the formal education system, long-term. We hope that all those to whom we have addressed these recommendations will take into account the importance of improving public understanding of science. But **our most direct and urgent message must be to the scientists themselves: Learn to communicate with the public, be willing to do so and consider it your duty to do so.**

ANNEX A

List of those submitting evidence

Oral evidence
Sir Geoffrey Allen, F.R.S.
Association of British Science Writers Executive Committee
Professor G.A. Barnard
Mr R. Bedford, O.B.E.
Sir Richard Cave
Dr B. Dixon
Sir Michael Edwardes
Sir David Hancock
Dr V. Harrison
Lord Hunt of Tanworth
Mr F. Jarvis
Mr M. Kenwood
Mr D. Lea, O.B.E.
Mr W. McCall
Sir Robin Nicholson, F.R.S.
Parliamentary and Scientific Committee
Professor C.A. Russell
Sir Peter Swinnerton-Dyer, F.R.S.
Mr A. Williams

Written evidence
Dr A. Abrahami
Dr E.J. Alford
Association of British Science Writers
Association for Science Education
Biochemical Society
Mr M.K. Bowker
British Academy
British Association for the Advancement of Science
British Broadcasting Corporation
British Gas Corporation R&D Division
British Medical Association
Mr M. Brown
Professor R.Y. Calne, F.R.S.
Chief Scientific Adviser, Cabinet Office
Chief Scientist, Department of the Environment
Ciba Foundation
Confederation of British Industry
Dr N.T. Crosby
Mr H. Daybell
Department of Education and Science
Department of Employment
Department of Trade and Industry (Industry–Education Unit)
Dr B. Dixon
Fellowship of Engineering
Mr D. Filkin
Mr B. Gee
Mr W. Gunston
Health and Safety Executive
ITN Channel 4 News
Institute of Biology

Institute of Mathematics and its Applications
Institute of Physics
Institute of Physics—Nuclear Interaction Group
Institute of Physics—Editorial Board of *Physics Education*
Institute of Statisticians
Institution of Chemical Engineers
Institution of Civil Engineers
Institution of Mechanical Engineers
Professor R.W. Lewis
Manpower Services Commission
Ministry of Agriculture, Fisheries and Food
Nature Conservancy Council
Parliamentary and Scientific Committee
Dr P. Pockley
Mr O.N.R. Potier
Mr H.E.G. Powers
Press Association Ltd
Dr B. Prestt
Royal Institution
Royal Meteorological Society
Royal Society of Chemistry
Royal Statistical Society
Science Technology and Society Association
Secondary Heads Association
Standing Conference on Schools' Science and Technology
Standing Conference of University Information Officers
Dr G.P. Thomas
TVS
Sir Denys Wilkinson, F.R.S.
Professor J. Tuzo Wilson, F.R.S.

ANNEX B

Visits and seminars

Visits were made to the following organizations:

- *The Guardian*
- ITN Channel 4 News
- *New Scientist*
- Science Museum, South Kensington

Members of the Group gave seminars to or in conjunction with the following organizations:

- Association for Science Education
- British Association for the Advancement of Science
- Chelsea College Centre for Science and Mathematics Education
- Institution of Mechanical Engineers (Interdisciplinary Committee)
- London University Department of Extra-Mural Studies
- Oxford University Department for External Studies
- Parliamentary and Scientific Committee

ANNEX C

Selected bibliography

This bibliography lists some of the items that have been found useful in the preparation of this report. It is not presented as a critical review of the literature on public understanding of science.

Surveys

Adult Literacy & Basic Skills Unit, *Literacy & numeracy: evidence from the National Child Development Study* (1983).

Cohen, A.V. & Mackay, C.J., 'Work-related and other risks: public attitudes, worries and concerns', *Employment Gazette* (1985), 70–72.

Commission of the European Communities, *Science and European public opinion* (CEC, 1977).

Commission of the European Communities, *The European public's attitudes to scientific and technical achievement* (CEC, 1979).

Commission of the European Communities, *Public opinion in the European Community: energy* (CEC, 1982).

Commission of the European Communities, *The Europeans and their environment* (CEC, 1983).

Department of Health and Social Security, *Smoking attitudes and behaviour* (HMSO, 1983).

Etzioni, A. & Nunn, C., 'The public appreciation of science in contemporary America', *Daedalus* **103** (1974), 191–205.

Garfield, E., 'Is public confidence in science declining?', *Current contents* **45** (8.11.82), 5–13.

Herman, R. & Kenward, M., 'What do people think of science?', *New Scientist* **105** (21.2.85), 12–16.

Hills, P. & Shallis, M., 'Scientists and their images', *New Scientist* **67** (28.8.75), 471–475.

La Porte, T.R. & Metlay, D., 'Technology observed: attitudes of a wary public', *Science* **188** (11.4.75), 121–127.

La Porte, T.R. & Metlay, D., 'Public attitudes toward present and future technologies: satisfactions and apprehensions', *Social studies of science* **5** (1975), 373–398.

Lee, T. *et al.*, *Psychological perspectives on nuclear energy* (University of Surrey Department of Psychology, 1983).

Market & Opinion Research International, *Attitudes to new technology—an international survey* (MORI, 1984).

Mazur, A., 'Public confidence in science', *Social studies of science* **7** (1977), 123–125.

National Science Board, *Science indicators 1982* Pion, G.M. & Lipsey, M.W., 'Public attitudes toward science and technology: what have the surveys told us?', *Public opinion quarterly* **45** (1981), 303–316.

Prescott-Clarke, P., *Public attitudes towards industrial, work-related and other risks* (Social and Community Planning Research, 1982).

Taviss, I., 'Survey of popular attitudes towards technology', *Technology and culture* **13** (1972), 606–621.

Wall Street Journal (Europe), 'European panel: business executives acknowledge they are lagging badly in technology revolution', *Wall Street Journal (Europe)* 31.1.84.

Walsh, J., 'Public attitude to science is yes, but—', *Science* **215** (15.1.82), 270–272.

Education

Advisory Council for Adult and Continuing Education, *Basic science education for adults* (ACACE, 1981).

Assessment of Performance Unit, *Science in schools* (DES, various, 1981–85).

Association for Science Education, *Alternatives for science education* (ASE, 1979).

Association for Science Education, *Education through science* (ASE, 1981).

British Gas, *Catalogue of selected resource materials* (1984).

Cairncross, A., *Science studies* (Nuffield Foundation, 1980).

Department of Education and Science, *Science education in schools: a consultative document* (DES, 1982).

Department of Education and Science, *Mathematics counts* (the Cockcroft report) (HMSO, 1982).

Department of Education and Science, *Blueprint for numeracy* (1983) (on the Cockcroft report).

Department of Education and Science, *AS levels* Consultative document (May 1984).
Department of Education and Science, *Better schools* (Cmnd 9469, HMSO, 1985: also available in summary from DES).
Department of Education and Science, *Science 5–16: a statement of policy* (HMSO, 1985).
Department of Education and Science, *Curriculum matters* (vols 1 onwards) (HMSO, 1985).
HMI Science Committee, *Science in primary schools* (DES, 1983).
Leach, D., 'A science-based generalist degree: science with industrial studies', *Studies in higher education* 3 (1978), 187–204.
Manpower Services Commission, *Open Tech task group report* (June 1982).
Manpower Services Commission, *Working in laboratories* (1982).
Manpower Services Commission, *Working in electrical and electronic engineering* (1982).
Manpower Services Commission, *Working in science* (1983).
National Academy of Science, *Science for non-specialists: undergraduate science education* (NAS, 1983).
National Academy of Science, *Science for non-specialists: improving college science education* (NAS, 1983).
National Academy of Science, *Science for non-specialists: understanding the science knowledge needs of the non-science professions* (NAS, 1983).
Royal Society, *Science education 11–18 in England and Wales* (Royal Society, 1982).
Science Studies Committee, *The significance of science studies* (Council for Science and Society, 1984).
Secondary Science Curriculum Review, *Science education 11–16: proposals for action and consultation* (SSCR, 1983).
Solomon, J., *How can we be sure?* (SISCON–ASE–Blackwells, 1983).
Young, D., 'Coping with change: the new training initiative', *Journal of the Royal Society of Arts*, (1984), 449–459.

Science and the media

American Chemical Society, *The chemist and the media* (ACS, 1982).
Birmingham University Information Office, *Can I quote you on that?* (1983).
Bragg, L., 'The art of talking about science', *Science* **154** (30.12.66), 1613–1616.
British Association for the Advancement of Science, *Science and the media* (BAAS, 1976).
Broad, W.J., 'Science magazines: the second wave rolls in', *Science* **215** (15.1.82), 272–273.
Crane, R. & Boswall, J., *Bibliography of the public's knowledge of and attitudes towards animals* (BBC Natural History Unit, 1982).
Department of Education and Science, *Popular TV & schoolchildren* (1983).
Gastel, B., *Presenting science to the public* (ISI Press, 1983).
Goodfield, J., *Reflections on science and the media* (American Association for the Advancement of Science, 1981).
Jerome, F. (ed.) 'Science in the media', *SIPIscope* **10** (1982-83), 1–19.
Jones, G., Connell, I. & Meadows, A.J., *The presentation of science by the media* (Primary Communications Research Centre, 1978).
Perlman, D., 'Science and the mass media', *Daedalus* **103** (1974), 207.
Ryder, N., *Science, television and the adolescent* (Independent Broadcasting Authority, 1982).
Silverstone, R., 'Science and the media: the case of television' (Colmar II colloquium, April 1985).
Singer, A.E., 'Science broadcasting in Britain', *Science* **154** (11.11.66), 743–745.

General

Abrams, N.E. & Primack, J.R., 'The public and technological decisions', *Bulletin of the atomic scientists* **36** (1980), 44–48.
Alt, M.B., 'Four years of visitors surveys at the British Museum (Natural History) 1976–79', *Museums journal* **80** (1980), 10–19.
Bailey, D.E. *et al.*, *Mathematics in employment (16–18)* (University of Bath, 1981).
Bauer, P. & Brochet, C., 'Pop physique 77', *Physical Education* **14** 1979, 243–245.
Bell, J., 'How to pack a public lecture', *New Scientist* (24.11.83), 584–585.

Bodmer, W.F., 'Understanding statistics' (Presidential Address to the Royal Statistical Society, April 1985).
Bondi, H., 'The making of a scientist', *Journal of the Royal Society of Arts* (June 1983), 402–410.
Calder, R., 'Science and the public', *Journal of the Royal Society of Arts* (March 1969), 269–279.
Collins, H. & Shapin, S., 'Uncovering the nature of science', *THES* (27.7.84), 13.
Culliton, B.J., 'Science's restive public', *Daedalus* **107** (1978), 147–156.
Daedalus **112** (1983): special issue on 'Scientific literacy'.
Department of Health and Social Security, *Report of the Committee of Inquiry in human fertilization and embryology* (the Warnock Report) (Cmnd 9314, HMSO, 1984).
Department of Trade and Industry, Overseas Information Unit, *Science Boutiques* (DTI, 1984).
Dixon, B., *What is science for?* (Collins, 1973).
Gonzalez, H.B., 'Scientists and Congress', *Science* **224** (13.4.84), 127–129.
Gregory, R., 'The Bristol exploratory—a feeling for science', *New Scientist* (17.11.83), 484–489.
Griggs, S.A. & Alt, M.B., 'Visitors to the British Museum (Natural History) in 1980 and 1981', *Museums Journal* **82** (1982), 10–19.
House of Lords Select Committee on Science and Technology, *Hazardous waste disposal* (HMSO, 1981).
House of Lords Select Committee on Science and Technology, *Research and development in the engineering industries* (HMSO, 1983).
House of Lords Select Committee on Science and Technology, *Education and training for new technologies* (HMSO, 1984).
House of Lords Select Committee on Science and Technology, *Local Government Bill: Scientific and technical services* (HMSO, 1985).
Kurtz, E., 'Public understanding of science', *Science* **154** (11.11.66), 800–801.
Lucas, A.M., 'Scientific literacy and informal learning', *Studies in science education* **10** (1983), 1–36.
Morison, R.S., 'Limits of scientific inquiry', *Daedalus* **107** (1978), vii-xvi.
Nelkin, D. & Rip, A., 'Distributing expertise: a Dutch experiment in public interest science', *Bulletin of the atomic scientists* **35** (1979), 20–23.
Pearson, R., 'Is all science vocational?', *Nature* **310** (19.7.84), 260.
Perl, M., Primack, J. & von Hippel, F., 'Public-interest science—an overview', *Physics Today* **27** (1974), 23–31.
Pockley, P., 'A national program for promoting public understanding of science' (paper presented to 53rd ANZAAS Congress, May 1983).
Prewitt, K., 'The public and science policy', *Science, technology and human values* **7** (1982), 5–14.
Raleigh, C.B., 'Scientists' responsibility for public information', *Science* **213** (31.7.81).
Shelton, W., 'Is science selling its story?', *University of Edinburgh Bulletin* **19** (1982).
Swedish Council for Planning and Coordination of Research, *Towards better knowledge: public understanding of science in Sweden* (Forskningsraadsnamnden, 1984).
Tudge, C., 'Hating science is wrong', *New Scientist* (7.4.83), 37.
University of Birmingham, *Working with industry & commerce* (1985).
Zuckerman, S., *Advice and responsibility* (O.U.P., 1975).
Zuckerman, S., 'Scientists, bureaucrats and ministers', *Royal Institution Proceedings* (1984).

850 85
Printed by Inprint of Luton Limited
95-115 Windmill Road, Luton, Bedfordshire, LU1 3XS