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Connecting Science

What we know and what we don't know about science in society

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PREFACE

Helen Haste

The BA is committed to public engagement with science and to science communication activities that reflect a dialogue approach. This is consistent with the recommendations of the House of Lords Select Committee, chaired by Lord Jenkin, in 2000, which defines dialogue in terms of the open exchange and sharing of knowledge, ideas, values and beliefs between scientists, the public(s), stakeholders and decision-makers[1].

As we recently noted:
"Dialogue is not primarily about providing a platform for scientists to explain to the receptive layperson how the world works. It is instead a context in which society (including scientists) can address the issues that are arising from new developments in science. Science should not be expected to have sole responsibility for the future of such developments; there is a responsibility to society to involve all citizens in decisions to the extent that this is possible.

"Dialogue does not remove authority or expertise from science; it locates scientific developments in a wider social context and enables the inclusion of a wider range of relevant expertise with regard to the application of such developments" [2]

In all its activities and projects, the BA attempts to implement this approach.

What do we need to know, in order to make dialogue work?

The purpose of the Review

Much has been going on in research, in the development of policy, education and communication, and in the evaluation of practice. We have produced this Review of the current state of knowledge about science communication, dialogue, public interests and aspirations about science, public concerns and trust, and perceptions of risk and ethical issues.

It is time to take stock of this body of knowledge and consider how it informs best practice, and what is missing, in our understanding of how dialogue can work effectively. This Review will hopefully be of value to those concerned with science communication and dialogue. It will also suggest areas in which the BA may initiate or foster further research and practice to address key questions.

Where are the gaps?
What remains to be investigated, and how might the BA be involved?

The Review covers recent research about:

- the public's perceptions of scientists, scientific developments, risk and ethics
- scientists' perceptions of the public and of science communication
- sources of information about science, including the media and both formal and informal educational resources
- science policy
- ethics and science
- principles of public participation and engagement in science

The Foreword presents a summary of each of these areas, and discusses possible research questions that arise within each.

The potential roles of the BA

Our conclusion from the Review is that there are three different activities in which the BA can take a major role:

- **acting as a 'broker' for the dissemination and discussion of current and recent research developments**, bringing together researchers from different fields and disciplines, and bringing researchers together with stakeholders, policymakers and the public. In doing this, the BA can become positioned as the primary resource for partnership in dialogue and engagement with specialist organisations and the scientific community. Maintaining and regularly updating the data reflected in the Review will keep the BA at the forefront of knowledge about science and society, and so maximise our value as a resource.

- **conducting, or commissioning, research of a pragmatic nature that fills identified gaps**. By 'pragmatic' research we mean primarily fact-finding, such as, for example, the question of where people currently gain their knowledge about scientific matters, and what developments are taking place in different educational contexts. Such a factual database would be of considerable use to a range of organisations and to members of the public.

- **providing the crucible for developing research which goes into greater depth about values, beliefs, motives, images and concerns**. Much current knowledge about the public's perceptions of science has been based on general questionnaire research which elicits agreement and disagreement with attitude or belief statements. Research that goes beyond such methods, particularly research which explores areas of ambiguity and tensions between apparently inconsistent values, reveals a much more elaborated picture which is ultimately more useful to policy-makers, as well as contributing more richly to scientific understanding of beliefs and values. For example, we know how much people 'trust' scientists – but what in fact does 'trust' mean in this context? Understanding what lies behind ethical concerns about scientific progress requires more than measuring how *strongly* the respondent feels on the issue.

The BA is particularly well placed to work with researchers across disciplines and domains to develop proposals for future research which can explore in depth the infrastructure of public concerns, the nature of trust, and how people deal with complex values and ethical decisions. Such consultations can vary from one day seminars to extended working groups or advisory bodies.

Summary of Research Questions

Three kinds of research areas emerge from the Review: under each we define a number of specific questions.

Pragmatic questions, gathering factual information:

- *how are science information resources used by the public?*
- *what do people want to know and by what means do they prefer finding out?*
- *how is the Internet used currently for public discussion about issues relevant to science communication and dialogue?*
- *how can we develop methods for assessing and evaluating 'informal' learning in interactive contexts?*

How can dialogue and communication be managed effectively?

- *how does dialogue actually work, both at the level of the dialogue process itself, and in terms of its long-term cultural effects?*
- *how effectively do people feel able to influence the government and society at large on matters that concern them relating to science and technology?*
- *how do scientists and journalists understand and negotiate their different agendas and assumptions?*

What are the key issues around values and approaches to knowledge that underpin public concerns in relation to science and technology?

- *what is the nature of ethical concerns, and on what value and assumptions do these rest?*
- *what governs how people select the knowledge that they 'need to know'?*
- *what are the varying kinds of 'trust' and their implications for public engagement with science and technology?*
- *how do people manage perceived tensions between values and science?*
- *how can necessary 'expertise' be identified and how is the credibility of 'lay' expertise established?*
- *how do scientists, and science teachers, conceptualise 'scientific truth', and how are ambiguity and uncertainty in scientific progress managed?*
- *what do young people want from the science curriculum, to make it more interesting and relevant, and to reconcile science and technology with value issues?*

A corollary of these value and knowledge questions is also how they are addressed and negotiated in dialogue.

FOREWORD

Helen Haste

As is well known, the House of Lords 2000 report on Science and Society, chaired by Lord Jenkin, specifically moved beyond the model of science communication implied in the recommendations of the Royal Society committee chaired by Sir Walter Bodmer in 1985, in which 'public understanding of science' came to be interpreted as the transfer of knowledge from scientific experts to a – largely ignorant – public [3]. This is now generally referred to as the 'deficit model' – empty vessels needing to be more effectively filled.

Things have also moved on since 2000; experience of 'dialogue' and public discussion has made scientists, science communicators and policy-makers aware that dialogue is particularly to be encouraged at an early stage in the process of new developments, when possibilities, problems, ethical issues and risks are being projected rather than at a point when public anxieties have become polarised. The terminology which expresses this is 'upstream' rather than 'downstream' engagement.[4]

These developments are cumulative rather than exclusive, since it is equally important that dialogue takes place in productive ways when engagement is taking place 'downstream' - when developments are in train and the public, policy-makers and regulators are responding to situations. Increasing public understanding of science remains a desirable goal, and in particular, increasing public awareness that scientific knowledge is cumulative and often provisional.

The changing approaches over the past two decades reflect a change in emphasis (from a 'top-down' to a more distributed model of knowledge transfer) and also a greater appreciation that merely explaining or conveying information does not necessarily lead to greater understanding or public trust. It is also important to recognise that 'increasing trust' can be a version of the 'deficit model' if its goals are primarily palliative; the desirable outcome is not compliance but informed critical engagement.

We stand at an interesting time; there is considerable support for effective engagement between the scientific community and the public, from all sides, and a widespread commitment to finding how best to achieve this. There are opportunities for reconfiguring the field which could have a major impact on the relationship between science and the broader culture.

Dialogue: what it is and what it is not

While the move towards greater dialogue has been widely welcomed by the public, policy-makers, science communicators and scientists, there have been caveats and criticisms. Some of these relate to pessimism about how effective dialogue can be, some to a misunderstanding of the intent.

First, it is not the purpose of dialogue to intrude upon the discussion amongst the science community about scientific knowledge. There is no suggestion that the progress of scientific ideas should be democratically decided.

Second, concern has been expressed that consultation can provide a whitewash – if things go awry in the wake of some future development, the fact that 'the public' was consulted might be used as a way of authorities denying responsibility. This at very least would lead to public cynicism[5]. Along similar lines, consultation and public debate can be a palliative without power; the opportunity for lively discussion can produce a 'feel-good' factor which can mask the actual ineffectiveness of critique, if the mechanisms for influence are not in place.

Third, there has been some concern that the goals of dialogue are primarily to increase trust in the authority of science and scientists through making more transparent such procedures as peer review, or to ameliorate anxiety through a more 'rational' understanding of risk. If this is seen merely as a way of conveying more 'top-down' knowledge from the experts, or justifying current practices, and does not engage with the actual concerns and values of the public in their terms, it is no different from the 'deficit model' [6]

What is dialogue about?

In 2000, Sir Aaron Klug, then President of the Royal Society, eloquently if somewhat instrumentally, articulated why scientists must become engaged in effective dialogue:
"Dialogue is about science's licence to practise. Science is, necessarily, run by scientists but it is ultimately society that allows science to go ahead and we need to make sure that it goes on doing so. So we need input from non-experts to make sure that we are aware of the boundaries of our licence; and, conversely, we need good channels of communication if we want to extend those boundaries, for example into new areas of research." [7]

We see three broad categories of purpose for dialogue[8]:

- increasing democracy by promoting open and transparent decision making
- greater trust and confidence in the regulation of science and the decisions taken and
- that better decisions will have been taken.

These three categories are based on Daniel Fiorino's arguments for public participation in environment decision making[9]

The first purpose, *increasing democracy*, refers to extending the range and number of people empowered to talk about science issues, improving public capability to influence local and national science-related plans and proposals. By making science more accessible through effective communication of scientific ideas and developments, and engaging and motivating lay people in an active understanding of scientific knowledge in a social, environmental and practical context, it is assumed that they will feel able to contribute to public discussion about scientific policy. This is the **normative** view of public engagement.

Dialogue should serve a second purpose of *building greater trust and confidence in the regulation of science and in scientific institutions*. Through consultation and greater transparency about decision making in relation to new developments, and recognising and acknowledging public interests and concerns, dialogue will reduce conflict between the science community, the regulators and publics. The second purpose of dialogue is an **instrumental** view.

Thirdly, dialogue should *improve the quality of policy decisions* by including a broader range of knowledge and considering how to develop science in ways that benefits society. This includes recognising the role of relevant expertise which may lie outside the boundaries of 'academic' science, including local knowledge or practical experience. The decisions are taken not just to improve the reputation of science or that of those making the decisions, but to improve the quality of our life. This is a **substantive** perspective.

Throughout all of this is the underlying need for scientists and policy makers to *acknowledge public views and opinions as legitimate*. Therefore, a starting point for dialogue is that many categories of people have an interest in, and indeed expertise relevant to, developments in science that affect them. Furthermore, allowing only one group of 'experts' to define the terms of reference will constrain what is included in the deliberations – at cost to the value of the discussion, as well as to the credibility of those discussions amongst the wider public who are affected by them.

There are several examples, noted in more detail in the Review, of problems that arise from not taking account of local expertise (in the case of the aftermath of Chernobyl), of debates in which participant groups were seen as biased by self-interest (as in the GM debate), and of misguided reluctance to recognise how people actually perceive risks to themselves, and instead imposing 'probabilistic' models which fail to motivate appropriate action. More successful consultations, including the stem cell debate, have been marked by the full involvement of a range of experts, including client and patient groups, social scientists, and ethics experts, in addition to the biological scientists involved in the work itself.

Dialogue is not particularly easy, but barriers can be overcome.

The Review describes research which provides guidelines towards this, as well as suggesting further lines of research to improve dialogue. Dialogue is most effective where each participant's assumptions and lay theories can be explored so that the group can fully understand what is shared and what is not. One important barrier is the quite reasonable anxiety that many scientists have of being able to communicate complex ideas to non-specialist colleagues. In fact the whole point about dialogue is finding a common language and understanding[10]. Where social and ethical factors are relevant in addition to scientific information – as they frequently are – the effective citizen-participant (and this includes the scientist) draws upon a variety of resources for discussing issues of equity, regulation, access and trust, as well as consequences, and there can be sophisticated debate.

A particularly successful example – and useful for demonstrating the processes of dialogue – comes from an activity which involved BA staff. This was an OST Foresight exercise in new developments in cognitive systems; research in computer science and neuroscience. The exercise brought together leading researchers from different disciplines with non-scientists, to see if the team could "sensibly discuss options and priorities ....and generate some common language for discussion, despite being unfamiliar with the detail of the leading-edge science. In other words, we wanted to establish some sort of more anticipatory form of technology assessment which might, if introduced more generally, be expected to take into consideration a broader range of opinions rather than just scientific expertise.

Perhaps unsurprisingly, we found that if the discussion was organised around questions such as benefits, concerns and moral issues both the scientists and the non-scientists could have very constructive discussion. The findings indicated that scientists and public participants shared the same dreams, hopes and fears for these new technologies."[11]

What we know, and where we might go next

The purpose of this Review is in part, to consider what we know about the conditions that predicate dialogue, and in part to consider what might be the next steps in useful research to facilitate the development of effective dialogue, whether 'upstream' or 'downstream'[12].

To do this, we must ask first, *where are people coming from*? What is their starting point – of knowledge, anxiety, image or ethical concern? What *more* do we need to know, in order to understand how those starting points can impede, or be used constructively towards, dialogue? How are concerns, anxieties, expectations etc organised? For example, risk and ethics are often conflated; it is not always clear whether objections to some developments are on moral grounds, or on grounds of possible consequences, or both – cloning is an example. We know quite a lot about the mapping of survey responses to attitude statements which require agreement and disagreement; however the effective pursuit of dialogue requires a greater understanding of what *underlies* those attitude scales, and how people *use* their values in decision-making.

Second, how do people *manage uncertainty and inconsistency*? The material on risk perception for example shows that people live comfortably with a high level of uncertainty under certain conditions. We also know that people seek only such information as they feel they 'need to know' – whether to reduce anxiety, or to reduce simple information overload. What governs the criteria for how people select what it is that they 'need to know'?

Another finding is that being sceptical about scientific developments does not exactly correlate with lack of scientific knowledge. *Those who are most interested in science may also have the greatest level of concern about ethical and other issues*. How is this apparent 'inconsistency' managed?

These general issues arise in several places in the Review. Let us consider each of the sections of the Review, and what emerge as areas for potential research. We identify three different kinds of research.

• First there are questions which are primarily ***pragmatic,*** and can be answered by 'fact-finding' studies, such as where people gain their information about science.

• Second there is the question about ***how dialogue works in practice***. What makes for effective communication, what skills do participants need to learn and use, what goes on in a negotiation, particularly between people who bring different assumptions and expertise to the discussion? This question is primarily addressed by research on the processes of dialogue itself.

• Third there are questions about the underlying assumptions that the science community and the public bring to the issues under concern. These include ***values***, particularly about ethics and about the quality of life including acceptable levels of risk, but they also include beliefs about ***approaches to knowledge***; how, for example, should 'uncertainty' be managed? How should the relationship between values and science be handled?

Section 1: Public understanding, perceptions and attitudes in relation to science, technology and risk

There is extensive material based on surveys about the public's attitudes to scientists, science and technological development, including perceptions of risk, ethical concerns and the extent of trust . Much of this work is based on attitude scales, and some on the relationship between attitudes – on ideologies, or 'value sets'. This is on the whole well-mapped territory. There are however some important demographic gaps, most particularly in relation to minority and ethnic groups.

What is also missing is a more subtle understanding of ***how attitudes and values are managed***; when we make decisions we give salience to different values in different situations. Also, we live quite successfully with inconsistency and uncertainty. In practice, we selectively seek information according to what we actually think we 'need to know'. One paradox is that laypeople are relatively ignorant of large areas of science, yet function perfectly effectively in those areas which are important to their lives, seeking such knowledge as is 'useful'. The selection of 'useful' knowledge also governs the kind of information people draw upon in making decisions about risk and also about ethics – and this selection is not necessarily according to the criteria that risk 'experts' would prefer. To improve dialogue, we need to understand more about what governs the 'need to know' principle, in different contexts.

The domain of ***risk perception***, as we see from the Review, has been rather richly researched; we understand the complex processes by which people manage risk – and the difference between the scientific 'expert' model and the lay versions. This gives us a good basis for approaching dialogue about how people with different interests manage the various elements in risk evaluation – an essential feature in developing risk policy. Other areas seem to need more attention.

Trust, for example, although well documented in terms of who trusts, and what is trusted, remains an area where it is not entirely clear *on what basis trust is formed*. We know that trust in scientists is variable, depending on who their employers are. However, 'trust' is a complex idea, and we need to know more about what constitutes it. Is trust about truth-telling, or about taking responsibility? Trusting a scientist to give impartial advice is a different thing from trusting them to recognise the possible consequences of their work. Why - apart from obvious issues of presumed vested interest – are some scientists trusted more than others? To what extent, for example, is trust in scientists deference to authority, or a priestly caste, and to what extent is it earned – and if so, by what?

Closely related to the management of inconsistency and uncertainty are the findings that ***those who are most informed about, and most interested in, science are also those most concerned about ethical and risk issues***. This may seem counterfactual; we might, at a commonsense level, predict that concern about possible risks and ethical issues would accompany a strong critique of science, particularly among young people. It seems however that a high level of interest in science leads to an unwillingness to separate the value dimensions from the technical; such people do not want to retreat into seeing science as 'value-free' but want to understand it in its larger context. It is a disservice to them to avoid uncertainties and ambiguities, and it is an impediment to dialogue to do so. A particular category for concern is young girls, who do not want to separate ethics and science, yet are often offered a model of science in school which tries to avoid ambiguities and value issues, potentially inhibiting their interest in pursuing science because the 'story' is incomplete.

The research question arising from this is ***just how do people manage the relationship between values and science***? This question can best be addressed by in-depth methods which explore how people dialogue about balancing and evaluating different elements in the situation, or how they manage their own internal value tensions – this is similar to the methods we see used successfully in risk evaluation, or in the Foresight exercise. Until we understand the subtleties of this, there remains a temptation to assume that concerns about ethical or risk issues reflect a negative attitude towards scientific and technological progress.

The question of ***'expertise'*** arises frequently in the Review. As we have noted, a driving issue in the expansion of dialogue has been the inclusion of a wider range of expertise, and particularly, how to harness such expertise effectively.

But what is an 'expert'? How do people become experts, and how do they become credible as experts – particularly where there is no obvious professional or educational route through examinations or similar hurdles. There is a large literature on the learning processes of becoming 'expert' which we do not address in the Review, but the question for dialogue is how relevant expertise is – or should be - identified by decision-makers, and how *credibility* is established.

Summary of Research Questions:

All the research questions fall into the category of 'Values and Approaches to Thinking' but also impact on how they are explored and negotiated in dialogue.

- ***what governs the selection of what we feel we 'need to know'?***
- ***what are the varying kinds of 'trust' and their implications for public engagement with science and technology***
- ***how do people manage the tensions between values and science***
- ***how can necessary 'expertise' be identified and how is the credibility of 'lay' expertise established?***

Section 2: Scientists' views about public engagement

There has been considerably less research on scientists' views of the public than on the public's views of scientists. In general it seems that scientists are supportive of greater dialogue but their main concerns are lack of competence to communicate and the lack of recognition or reward for this activity, compared to research itself. The perceived barriers are skill, not attitude, as well as lack of validation of the activity by employers and peers. The Royal Society is currently exploring what scientists perceive to be the barriers to communication.

There is also a question of where responsibility for communication resides – is it with scientists, or is it also with the media? If scientists are the main source, then communication skills training is needed; if the media are, then the task is to find ways for journalists and scientists to work more effectively together. However, it is worth noting that even science journalists do not perceive themselves in general primarily as science communicators.

The effectiveness of various partnerships schemes, such as the BA Media Fellowship Scheme, and Royal Society Parliamentary partnerships, is well documented. There is a logistical challenge about how such experience can be made widely available to the science community. However there is not yet a great deal of research on how scientists approach the 'dialogue' process.

One point that emerges from the Review is a tendency for teachers (in particular) to purvey a model of science as being about factual truth, decontextualised, and without uncertainty. The extent to which scientists adhere to this perspective is unclear, but such a mindset about the nature of 'truth' would be a barrier to dialogue. There seems a very real gap between the routine acceptance – and tolerance – of ambiguity and uncertainty that is evident amongst those eminent researchers who write material for Royal Society documents on science and society, and the message that schoolchildren seem to get. Research on the underlying model that the majority of scientists have of science seems a necessary prerequisite to appreciating the problems of dialogue.

Summary of Research Questions:

The first research question falls into the category of 'Values and Approaches to Thinking', the second into the category 'How can dialogue be managed effectively?

- ***how do scientists, and science teachers, conceptualise 'scientific truth', and how is ambiguity and uncertainty in scientific progress managed?***
- ***how do scientists and journalists understand and negotiate their different agendas and assumptions?***

Section 3: Sources of information about science

The Review indicates that relatively is little known about how people actually gain information about science. In the promotion of more effective communication and dialogue, this would seem to be an area open for research.

We could usefully know more about how people do actually use the many resources available, and what they find most congenial. We could also usefully know whether different resources are used for different purposes. The increasing importance of the Internet for everyone needs to be explored – in particular because this is not only a source of factual information; it is also the locus of increasing debate and discussion. The government and science communicators are well advised to take advantage of this for exploring dialogue. However, it would be useful to research more extensively how people use the Internet for discussion.

Summary of Research Questions:

These are 'Pragmatic' questions:

- ***how are science information resources used by the public?***
- ***what do people want to know and by what means do they prefer finding out?***
- ***how is the internet used currently for public discussion about issues relevant to science communication and dialogue?***

Section 4: Science and the media

The Review throws up particularly the tensions between scientists and journalists, as well as areas where there has been constructive collaboration.

Much of the activity has been directed to skills improvement; how can scientists get better at communicating their work to a wider audience, and how can journalists learn to address the science-reading public more effectively? However, behind mutual recriminations about 'incompetence' – that scientists can't communicate, and that journalists can only communicate in a highly simplistic way – there are issues that are not resolved simply by skills training. One is reconciling the different agendas of the two groups; selling newspapers, which requires 'entertainment' at some level, and conveying the nuances and ambiguities of new science, yet without so many caveats that the story ceases to be interesting.

Such reconciliation requires more than acquiring skills for it reflects differing philosophies. It would seem timely to explore more fully what happens when scientists and journalists engage in dialogue about their respective roles and obligations to the public. It is perhaps ironic that excellent scientist communicators (those who tend to win the very few prizes which are an incentive for good science communication) manage to do this, bringing together the two agendas in their own work. Experience of Media Fellowships and similar partnerships suggest that what is happening to the participants is something along similar lines; a merging of philosophies in a productive way.

Summary of Research Questions:

The main question concerns management of dialogue:

- ***how do scientists and journalists understand and negotiate their different agendas and assumptions?***

Section 5: Science and education

This section addresses three main issues;
- first, whether the current school science curriculum serves the needs of all young people,
- second, how to attract more girls and ethnic minorities into science
- third, how informal science education works, through science centres, museums and also through literature and art forms.

The **science curriculum** is under scrutiny in part because it is located within a frame of 'scientific literacy' that has come into question – knowledge based, minimising uncertainty, and focused narrowly on preparing future science professionals. Increasingly there is pressure to produce a curriculum that involves first, more participation in the learning process, and second, more recognition of the wider social and environmental context of science and the skills needed to deal effectively – and critically – with that. 21st century science developments are moving to create such a curriculum, and the Working Group in 14-19 Reform, chaired by Mike Tomlinson (and published after this Review was complete) is likely to stimulate further re-consideration of the curriculum[13].

The **extent to which the existing curriculum serves girls** is also under review. Girls do better than boys in public examinations in science, as in most other subjects, but proportionally do not pursue the physical sciences and engineering at post-16, contributing to the current shortfall in expertise in those fields. The question of why girls are apparently 'turned off'' science has been part of the larger question of girls' under-achievement in the past. That achievement gap has now narrowed (and we are beginning to ask why boys don't achieve) but it seems that the very things that concern girls are those that are central to the larger public's perception of science; the separation of scientific and technological knowledge from the social and ethical context.

The research questions arising from these points link up with two questions addressed above; **how do science teachers see science** and the message that they wish to communicate – to what extent do they feel it necessary to isolate science from values, and also, how do girls (in particular) reconcile an often passionate interest in science with an equally passionate concern about ethics[14]?

The explosion of **science centres** and the changing ethos of **science museums** has produced a radical new approach to installations and displays, reflecting learning as an interactive process, and looking at science and technology in the larger context. This is itself symptomatic of an increasingly 'dialogic' perspective on communicating science, engaging and empowering young people. The Review makes it clear that a great deal of thought has gone into the philosophy of new approaches, and the educational processes involved.

However such approaches are not well evaluated by simple pre and post test factual knowledge measures. The range of learning in interactive experience requires many aspects to be addressed – from the cognitive to personal efficacy. Intensive and careful observation of what goes on in such a learning context needs to be done; such time and resource-consuming qualitative research has begun, but we will not be able to evaluate interactive learning properly until such work is done – nor know how to improve it.

Similarly, there is a large range of **other informal education** – all clearly engaging to participants, but as yet without adequate means of evaluation. We need to develop some consistent evaluation method which can be used with quite large numbers in the most informal of settings, at very least to measure the subjective impact of such experiences.

Summary of Research Questions:

One emergent question is 'pragmatic':

- ***how can we develop methods for assessing and evaluating 'informal' learning in interactive contexts?***

A second addresses Values and Approaches to Thinking:

- ***what do young people want from the science curriculum, to make it more interesting and relevant, and to reconcile science and technology with value issues?***

Section 6: Science policy

The Government's Ten Year Strategy for Science lays out a number of proposals which are supportive of dialogue promotion. Science policy proposals also advocate **'the knowledge society'** which implies considerably greater collaboration between the sciences and other domains, especially those fields which address ethical, social and economic issues, in the development of public policy in relation to science. These are encouraging developments which are also highly sensitive to possible pitfalls.

The research implications primarily concern **how dialogue works**. Much has been said about 'upstream' dialogue; intervening in the decision-making process at an early stage, where those concerned can explore projections, relevant issues and scenarios, rather than reacting to a crisis of public confidence. We have already noted the need for research on how dialogue is managed and how people learn to deal with diverse viewpoints (as in the Foresight exercise). Such analysis will be necessary for considering whether and how upstream dialogue is effective.

There are larger policy implications; not only what goes on within the dialogue, but how the dialogue itself is **embedded in the cultural (and political) debate** – and how it influences it. The stem cell discussions, for example, which are held up as a 'success' drew upon people who not only had a personal or group interest, and appropriate expertise, but were also located within society as opinion-formers, or as the conduit for decisions. Their future output, as well as their input into the discussions, was salient to judging the success.

Additionally, the inclusion of input from **non-science 'experts'** who are recognised as credible by the public, such as ethicists, meant that the exercise was seen not only as democratic in the sense of representative of views, but *culturally valid* in the sense of bringing in perspectives widely recognised as important to the debate. A similar process is being proposed for the upstream discussions of nanotechnology. There is, however, a danger that the involvement of experts in ethics (or risk) can remove responsibility from the science community (and from politicians) to address the issues as an integral part of development.

A valuable direction for research would be to monitor the progress of such upstream activities, which looks at their wider context and impact, as well as the micro processes of their conduct. A further elaboration of this is to find out whether one of the aims of the Ten Year Strategy, to improve trust, is achieved by such activities – not merely by a simple attitude scale, but along the lines of the proposed study of trust mentioned earlier - exploring the **nature and sources of trust.**

Summary of Research Questions:

One emergent research question addresses 'how dialogue works':

- ***how does dialogue actually work, especially in 'upstream' interventions, both at the level of the dialogue process itself, and in terms of long term cultural effects?***

A second addresses issues in 'values and approaches to thinking'

- ***what are the varying kinds of 'trust' and their implications for public engagement with science and technology?***

Section 7: Science and ethics

In addition to an overview of the principles of ethical and honest research practice, the Review explores some of the major areas in which there is ethical contention in public debate. These particularly include animal experimentation and genetic engineering. Within each of these there are questions about just exactly **what the ethical discourse is,** and also the question of **who should decide; where governance should lie**? For example, in dialogue about ethical issues, to what extent should end-users and funders be engaged?

As mentioned earlier, because of the style of most questions used in surveys, it is not always clear exactly what the 'moral' objections are – and where for example they shade into 'risk'. 'Interfering with nature' for example can be objected to because it may lead to unbalancing the equilibrium of the environment (a 'risk' consequence) or because it may be objected to on moral grounds on principle – the 'Frankenfood' debates consistently mix up these.

It is only by more in-depth probing questions, or in the context of dialogue itself, that the underlying assumptions (and how they need to be negotiated) become explicit. As with risk research where this unpacking has been done to a greater extent, our understanding would be enriched by getting beyond attitude scales that merely measure the ***strength, not the content*****, of ethical concerns,** and how **values are *used and negotiated* in dialogue**, not only what those values are.

This is particularly true in the case of genetic engineering; so far we know quite a lot about what ***purposes*** **are deemed acceptable** for the use of genetic engineering (of both plants and animals) but we know much less about what ***underpins*** **these concerns**. Wild Pandora's Box concerns about cloned dictators aside, the main issues about genetic engineering (of humans) seem to lie with governance (who should decide), or on the social equity issues of 'designer babies' (what effect will this have on future less-than-perfect beings, as explored fictionally in the film *Gattaca)*.

Although for many people this may be a gut reaction to 'interfering with nature' we should not underestimate the sophistication with which many laypersons without ethical training legitimately address these questions – but we need to know more about what is going on in the debate.

Summary of Research Questions:

The primary emergent question relates to 'values and approaches to thinking':

- ***what is the nature of ethical concerns, and on what value and assumptions do these rest***
-

But this is also entwined with 'managing dialogue"

- ***how are these negotiated in dialogue?***

Section 8: Public participation and engagement in science

The final section of the Review primarily concentrates on **recommendations for effective public engagement**, summarising the current position and drawing on recent documents, such as the very useful DEMOS report on 'upstream' dialogue[15]. This section however does raise one issue that implies a research need. Much of the Review has concentrated on 'engagement' in the sense of dialogue, consultation, opinion-seeking and democratic processes of representation. One dimension of public engagement is protest.

Protest can take many forms, but it may be a significant indicant of two things; the strength of opinion of the public (or at least some concerned members - protest can reflect the views of a small but vocal minority), and the culture of democratic action. Propensity to taking action is only one measure of the intensity of views, and it is also a reflection of how effective people regard such action to be. Britain has had much less of a 'protest' culture than some other societies. We have seen public protests around several issues touched on in this Review – such as the environment, and animal experimentation. The literature on protest shows that, in general, those who protest combine a high sense of personal effectiveness with low trust in the government.

This is well-trodden ground in the context of the conventionally 'political' domain. What we do not know is on what issues relating to scientific and technology progress, and for what reasons, the 'average' person **would consider taking action** – whether writing to a representative, or going as far as demonstrating. In the contentious areas that we have addressed in the report, there is little data on the general question 'what would you march for?' - or even vote on.

As ethical and contextual issues become more central to the process of dialogue, we must recognise that this brings the discussion of science and technology much more centrally into the **domain of 'citizenship'**. The 'citizen scientist' wants to – and should – be able to take more responsibility for the decisions that will affect his or her life. Dialogue is part of good citizenship, and the factors that govern other areas of citizen behaviour apply here also.

Summary of Research Questions:

The primary emergent research question relates to the effectiveness of dialogue:

- ***how effectively do people feel able to influence the government and society at large on matters that concern them relating to science and technology?***

INTRODUCTION

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The report "Science and Society", from the House of Lords Select Committee on Science and Technology in 2000[16], chaired by Lord Jenkin and known as the 'Jenkin Report', describes the present time as a "critical phase" in society's relationship with science. Recent controversies over BSE and GM food contributed to what the Committee identify as a "crisis of confidence" in science. At the same time, it identifies a "new mood for dialogue" amongst scientific institutions. This needs to be expressed in innovative public engagement activities and new institutional and governmental procedures for involving diverse groups in decision-making about science issues.

There are a number of reasons why the public should be engaged in science. Science is not just necessary for professional scientists – it is part of our everyday lives. The government and scientists need to engage the public and young people on issues relating to science in order to support investment in research and to encourage the take-up of science careers.

The public benefits from accurate and accessible scientific information for informing personal decision-making. In some cases, this information can be vital to our health and well-being. In addition, understanding scientific issues enables the public to exercise our democratic right to influence science policy. The Wellcome Trust states that some scientific developments are so fundamental that there needs to be a national consultation with the public before decisions are made by scientists or politicians[17]. As Dame Julia Higgins pointed out in her Presidential address to the BA Festival of Science in 2004, the public's involvement in science should to be increased to match its investment and the degree of risk to which it is exposed by scientific and technological developments[18].

Finally, engaging the public in dialogue about science issues will improve and legitimise the decision-making process and help rebuild trust in scientists and policy-makers, securing science's 'licence to practice'[19].

In moving forward with a strategy for dialogue, it is vital that we understand the relationship between science and society and the reasons why dialogue is necessary. This Review outlines the main developments in this broad field, principally in the context of Britain, and identifies areas in which further research is needed.

Unless otherwise stated, the term **'science'** is used in this Review as it was in the Jenkin Report – to refer to the biological and physical sciences and their technological applications. It is these areas of science that can provoke the greatest public reaction and misunderstanding and yet most directly affect our lives. As the Jenkin Report pointed out, the contribution of social science to this problem is to explain the processes of communication between science and society and to offer guidelines about how this might be improved[20]. However, the key messages contained in this report about how to effectively engage the public can be applied equally well in social science.

The term **'public'** is defined in this Review, as the general 'lay' population not specifically trained in a science, engineering or technology discipline. It is accepted that scientists are also members of the public and have 'lay' concerns; in fact, this report argues that understanding this improves the prospects for bringing science and the public closer.

- ***Section 1 of this Review examines the range of perceptions amongst the public in relation to science, scientists, technology, and risk. An understanding of public knowledge, values and beliefs – not only of those who are scientifically confident but also of people whose voices are not often heard in public debate – is vital to ensure productive and democratic dialogue between experts and non-experts.***

- ***In Section 2, the Review examines scientists' views about science communication and public participation in science issues.***

- ***The organisations, which are used by the public to get information, are considered ins Section 3, along with the levels of trust the public have in scientists.***

- ***The contexts in which the public learns about science – including formal education and 'informal' channels like the media, science centres and the Internet - are addressed in Sections 4 and 5.***

- ***The 10-Year Investment Strategy for Science, announced in July 2004, and the issue of science policy in general are the focus of Section 6.***

- ***Section 7 tackles ethical issues in the practice and application of science.***

- ***Section 8 outlines how dialogue between scientists and the public can effectively be achieved in order that public opinion can be integrated into decision-making about science issues.***

It is hoped that this Review will inform further research, debate and practice in public engagement in science.

1 PUBLIC UNDERSTANDING, PERCEPTIONS & ATTITUDES IN RELATION TO SCIENCE, TECHNOLOGY AND RISK

1.1 Public interest in science and technology

Public interest in science is generally high[21]. Recent research[22] found that:

- 70% of the British public agrees that 'science is such a big part of our lives that we should all take an interest'
- Only one-fifth agrees that they are 'not interested in science and do not see why they should be'
- Half of 11-21 year olds 'like learning about new developments in technology', and 'would like to understand a lot more about those areas of science that will affect me personally'[23]
- In general, women are less interested in science than men[24].

The areas of greatest interest to the public are consistently medical discoveries (87% in 2000 said they find these very or moderately interesting), followed by environmental issues (82%), new inventions and technologies (74%) and new scientific discoveries (71%)[25]. In fact, the proportion claiming to be interested in science is greater than the proportion interested in sport (60%).

The areas of science which attract most public interest are those that are seen to be of greatest potential benefit and of greatest relevance to people's own lives. As will be discussed further in Section 1.8, people find it hard to relate to information which does not resonate with their values, experiences and beliefs[26].

1.2 Public attitudes to science and technology

In general, the British public considers science to be beneficial. Although people in Britain and Ireland are more likely than elsewhere in Europe to associate science with negative local effects[27], they remain largely optimistic.

- Three-quarters of the British public are 'amazed' by the achievements of science
- Two-thirds of the British public, compared to 86% of the US public, agree that 'science and technology are making our lives healthier, more comfortable, and easier'[28].

A similar proportion of young people (aged 11-21) appreciate the benefits that science offers to their lives[29].

However, science is not merely appreciated at the level of individual gain. For example:

- Almost three-quarters of the public support basic research, which may not bring immediate benefit

- 80% support investment in science and technology to enhance national competitiveness[30].

Young people want to see more investment in a number of areas of science and technology, particularly 'finding a cure for AIDS' and 'making environmentally-friendly products'[31].

An appreciation of the importance of knowing about science has increased since 1996, although people are now more questioning about the benefits[32]. Despite widespread optimism about science, there seems to be some concern within British society over the use of science and the level of control society has over science.

- Only 43% of the public believe the benefits of science outweigh any harmful effects
- The same proportion feels that the speed of development in science and technology means that government cannot control it properly[33]
- Yet, only a minority (24%) goes so far as to say that science seems to be out of control[34].

Although the British public largely has faith in the purpose of scientific research, their faith in government is evidently much lower[35].

- Most people (70%) feel that the aim of science is primarily to improve human life
- A minority feel that it is to benefit business (11%) or to satisfy scientists' curiosity (11%)[36]
- Only 43% believe that politicians support science for the good of the country
- Half think that politicians are swayed by the media and that they should take more of a lead[37].

There is also concern amongst the public about the effectiveness of trying to control scientific researchers.

- Over two-thirds of people agree that regulations will not stop scientists doing what they want 'behind closed doors'
- Half think scientists try new things without stopping to think about the risks[38].

Younger people seem to be more trusting of scientists.

- While only a third of young people agree that they trust the government to make any necessary laws to control dangerous developments in science
- Over half trust scientists to make responsible judgements about the dangers of their work[39].

As will be discussed in Section 8, the public clearly feels it should have a greater influence in scientific research and policy[40]. The overall picture suggests that:

> "Although [the public] appreciates the positive contribution of science to society, most people feel scientific developments should not be trusted blindly, which can be interpreted that people show a degree of 'critical trust' towards science"[41].

1.3 Public attitudes towards scientists and technologists

The image that the public has of scientists influences how effectively scientists will be able to communicate their research. It also has an effect on whether young people will be attracted to a career in science, technology or engineering[42]. In recent years, the public's view of scientists has become somewhat ambivalent.

On one hand, the British public respects scientists and their opinions. For example:

- 84% of the British public feel that scientists and engineers make a contribution to society
- Two-thirds believe that scientists want to make life better for the average person[43].

It is clear that scientists' and other experts' opinions are seen by the public as important in political decision-making

- More than four out of five people feel that 'politicians need specialist help to regulate some areas'
- 62% accept that 'you have to trust experienced people to make decisions'.

Along with friends, family members and other people perceived to be similar to oneself, scientists are amongst the most trusted sources of information[44]

- In 2001, two-thirds of the British public (increasing to 79% of 15-24 year-olds) said they generally trust scientists to tell the truth[45].

In comparison, politicians, journalists and those working in industry are given little credibility by the public[46]. This varies somewhat between countries, with the US public trusting scientists more and distrusting newsreaders much more than the British public[47]. In general, there is an increasing tendency for the public to question those in authority, including – as described above – those in control of science[48].

However, despite generally commanding respect and trust, the public sees scientists as being 'not quite like us' and the research they do 'behind closed doors' is viewed with some suspicion[49]. The stereotype of a highly intelligent male in a white coat, leading a life of lonely dedication and unmotivated by wealth is still common[50], but the public increasingly distinguishes between areas of science in their perceptions of scientists. Medical researchers, for example, are more readily associated with women and considered more accessible and less isolated than cosmologists[51].

Furthermore, recent US research found gender differences in how scientists are perceived, with women less likely than men to hold negative perceptions[52].

The affiliation of scientists is fundamental in determining the trust they command. Studies[53] show that scientists working for universities are the most trusted sources of scientific information; 60% of people in 2002 agreed they trust university scientists[54].

Scientists working for research charities are also considered trustworthy[55]. By comparison, scientists who are considered to have vested interests are less trusted:

- A third of the public trusts government scientists
- Only 14% trust scientists who work for industry[56].

Consistent with this, people feel that scientific advice should be independent, three-quarters agreeing that 'it is important to have some scientists who are not linked to business'. Implicitly, the public rejects the idea that scientific research is automatically objective and reliable or that scientists can always be trusted to tell the truth[57]. Recognising this problem, the Jenkin Report advises that scientists openly declare sponsorship and affiliations and submit their research to peer review; and that expert panels represent a balance of interests[58].

1.4 Attitude variation amongst the British public

Beyond the overall picture, research[59] has identified attitudinal groups within the adult British public whose views about science vary. Box 1, below, summarises the main characteristics of these groups.

An analysis of the attitudes and values of young people aged 11-21 reveals similar patterns of differing views about science:

• Boys and young men are more likely to be 'Techno-investors' - enthusiastic about investment in science and technology and about the beneficial effects of science. They trust both scientists and government.

• The 'Science-Oriented' value set, which is largely associated with young men, includes interest in science programmes and science fiction, and belief that a 'scientific way of thinking' can be applied widely.

• In contrast to these, the 'Alienated from Science' value set reflects boredom with science and scepticism about its limitations. This value set is more likely to be associated with younger girls and young women in the workplace.

• Finally, girls are also more likely to have 'Green values', being concerned about ethical and environmental considerations and sceptical about 'interfering with nature'.[60]

Box 1 – Attitudinal groups with varying views about science

Percentage of the public	Main attitudinal characteristics	Demographic profile
20 %	**Technophiles** – positive about science and know how to access information but sceptical of politicians and the regulatory system	High-income, higher social grades, well educated, and younger people
17 %	**Confident Believers** - in science and interested in science because of the benefits it brings. Faith in the regulatory system and their capacity to influence government	Largely high-income, well-educated, middle-aged, more likely to live in the south of Britain
17 %	**Supporters** – amazed by science, engineering and technology and able to cope with rapid change. Belief that the government has control. Supporters are more likely than other groups to be interested in engineering and the physical sciences	Younger, higher proportion of people still in education
17 %	**Not Sure** – uninterested in science or topical issues, perhaps because the benefits of science are often not apparent in their daily lives. Consequently, this group have few opinions about science	Typically low-income (including those on state benefits) with a low level of education
15 %	**Not for Me** – uninterested in science or topical issue whilst appreciating the benefits of science for the future and its importance to young people	Mostly low-income women aged 65 and over and slightly younger male skilled manual workers
13 %	**Concerned** – interested in topical issues and know science is an important part of life, especially for their children. However, they are sceptical of those in authority	Higher proportion of women than men

Source: Office of Science and Technology and The Wellcome Trust (2000). *Science and the Public: A review of science communication and public attitudes to science in Britain*. London: Office of Science and Technology/The Wellcome Trust.

These more detailed analyses of public attitudes highlight a key theme that has emerged in recent science and society research[61] – that the public is not a homogenous group, but rather many 'publics' representing a range of diverse perspectives. Attitudes and beliefs in relation to science differ according to gender, age, education and other factors, such as attitudes towards life in general and beliefs about humans' relationship with and responsibility for nature. This diversity has implications for the design of appropriate science communication strategies that will appeal to different target audiences.

To date, little research has been carried out amongst ethnic minority groups to identify differences by ethnicity in attitudes towards science.

1.5 Public understanding of science and 'scientific literacy'

The 1985[62] Royal Society report on the public understanding of science produced by the committee chaired by Sir Walter Bodmer (the 'Bodmer Report') drew attention to the issue of 'scientific literacy' amongst the public. Much research since this time has measured the British public's understanding of science in relation to pre-defined scientific 'facts'. These studies have consistently found low levels of 'textbook' scientific knowledge and understanding of the process of scientific inquiry. This is despite widespread interest in science. For example:

- In 1988, only 34% of the British public knew that the earth goes round the sun once a year
- Only 17% spontaneously referred to experimentation and/or theory testing when asked what it means to study something scientifically[63].

However, the degree of tacit public understanding of the processes of science is higher, with over half the British public recognising the experimental approach from a list of options as the 'scientific' means of investigation[64]. The picture remained largely unchanged in 1996[65]. Most recently, a survey of the public's knowledge of a number of scientific issues found that the average correct score was 38%, rising to only 56% for those with a science degree[66].

Across Europe, too, a significant proportion of the public (30%) does not know what it means to study something scientifically'[67]. In the US, knowledge of scientific 'facts' and understanding of the scientific process is about as low as in the UK[68].

These studies show that **demographic factors affect scientific literacy**. Men, middle class people and broadsheet readers tend to be more knowledgeable about science. The strongest association is between educational level and scientific understanding.[69] In 1988, younger people were more knowledgeable about science than older people. However, more recent research that examined the public's understanding of climate change, MMR and genetic science[70] suggests that different ages are knowledgeable about different areas of science. The study found those aged 45-54 to be the most knowledgeable overall and the under 25s and over 65s to be the least knowledgeable.

People's self-assessment of their scientific understanding is often lower than the amount of science they actually know. Most people – even those with higher scientific knowledge – perceive a barrier to the average person understanding science.

- Two-thirds of the public believe that 'science and technology is too specialised for most people to understand it'
- 38% agree that they are 'not clever enough to understand science and technology'[71]
- Most people (79%) say they feel confused about scientific issues[72]
- Around two-thirds feel that 'there is so much conflicting information about science, that it is difficult to know what to believe'[73].

This suggests that some people find the inherent uncertainty of scientific evidence and instability of scientific theory difficult to accept, perhaps because the emphasis of science communication has been on the provision of scientific 'facts' rather than providing an insight into the continually questioning method of scientific discovery[74]. It seems, however, that girls and young women are more willing to accept ambiguity than boys and young men[75].

The assumption behind many science communication initiatives is that providing more scientific information, and increasing scientific literacy amongst the public, will foster support for science and technology[76]. Although there is some correlation evidence to support this assumption[77], research indicates that the relationship between knowledge and attitudes towards science is more complex. There may be many sources of an individual's attitude towards science. In particular, cultural and personal values will be central in determining one's evaluation of science, technology and their associated risks and benefits[78]. Rather than suggesting ignorance of the science involved, reactions to particular scientific developments (such as GM) may be based on valid preferences for personal safety and concerns about environmental damage.

Furthermore, understanding of political issues is likely to influence attitudes towards science and technology[79]. These influences will be discussed further in Section 1.8. Therefore, **rather than implying unqualified support for science, understanding of science is associated with more coherent and discriminating attitudes in relation to science**. While more knowledgeable members of the public are more positive about science in general, they may be less supportive of morally contentious areas of research[80]. Amongst young people too, those most interested in science (particularly girls) are more likely to be sensitive about ethical issues relating to science[81].

The way in which 'scientific literacy' has typically been defined and measured has been criticised as being **too exclusive and static, and ignorant of the contextual meanings and everyday uses of science**[82]. For example, a fundamental part of the public's understanding of science is their perception of science as a social institution[83]. So, "the image of science that people have may be more important than the facts and methods they know in building trust in science as an institution"[84].

One qualitative study [85] which examined non-scientists' understanding of the immune system, found that scientific knowledge is inextricably linked to other forms of knowledge and to social and ethical issues surrounding science. Another study found that values and social identities, rather than narrowly defined 'scientific' concepts, fundamentally determine the public's understanding of energy[86]. In many cases, 'science' does not appear explicitly in social life; rather it is "tacitly renegotiated" to form taken for granted knowledge and social practice[87]. As Levy-Leblond observes[88]:

> "Given the poor results of the scientific literacy tests, one would expect a terrible misfit of most people in this technocratic society. What is striking instead is that people are not that bad at mastering their highly elaborate and rapidly evolving technological environment… In fact, people show a rather uncanny ability to learn what they need to learn and not more".

This research suggests that a more useful definition of 'scientific literacy' would include **how individuals apply scientific facts and principles** to particular situations and express them in their understanding of the world. Researchers have highlighted the disparity between

- The content-based 'textbook' science traditionally taught in schools and against which scientific literacy has largely been evaluated
- The understanding that people need in order to deal effectively with scientific information in everyday contexts, for example in reading and evaluating media reports, and making personal decisions about health and diet[89].

In the light of recent and current controversies, such as mobile phone safety and BSE, scientific literacy for today's society needs to include an awareness of:

- How scientific information is obtained
- How reliable it is
- What its limitations are
- How it is used
- An understanding of key scientific theories and findings[90].

Major new initiatives, such as the Nuffield 21st Century Science project (discussed in Section 5), are redefining core elements of the necessary science literacy and science education to help people use science to "make sense of their lives" and to "take part confidently in discussions with others about issues involving science"[91].

This is especially important because for many young people, particularly girls, social and ethical concerns are integral to their interest in science. There is a danger that defining the 'scientific worldview' too narrowly in terms of a particular (stereotypically 'masculine') form of rationality[92] excludes a large proportion of the population from science. In fact, there is evidence that this 'gendering' of science has limited women's involvement and influence in science and resulted in more negative attitudes towards science amongst girls[93]. This issue will be further discussed in Section 5.

In summary, we have indicated that **'scientific literacy' is increasingly being seen in broader, more socially applied terms that focus on *why* the public needs to understand science.** Scientific literacy that is in the public interest distinguishes the scientific understanding that today's citizens need in order to make informed decisions, from that which most people can get along without. Future studies of the public's understanding of science will need to decide on and justify how they define and measure scientific literacy.

1.6 Scientific and other ways of understanding the world

Some people[94] have expressed concern that there appears to be a growing 'anti-science' culture within British society. They point to evidence, for example, of distrust in scientists, 'ignorance of scientific evidence' and 'irrational' reaction to risks. However, the evidence that we have already discussed shows that, although recent controversies have contributed to lower public confidence in science, the British public is interested in and optimistic about science. Although people who hold certain sets of values are less interested in science, the vast majority (91%) of the public agrees, "it is important that young people have a grasp of science and technology"[95].

Furthermore, as we have seen in Section 1.5, the public is not universally scientifically ignorant, but rather draws on scientific knowledge where it is needed in everyday decision-making.

The public's appreciation of science is accompanied by an awareness of the need to see the benefits of science in context and to question those who control science – something that might be seen as healthy in a democratic society. There is no evidence that environmental, ethical or religious values are inherently incompatible with or antagonistic to science[96]. As we have discussed**, the relationship between knowledge and interest in science, on one hand, and support for science, on the other, is not straightforward since different aspects of concern and support in relation to science co-exist**[97]. As we will discuss in Section 8, central to the principle of public engagement in science is the view that "lay values – which may indeed be shared by scientists – should indeed be part of the wider political debate"[98].

The public does not blindly trust science as the most authoritative or valid form of knowledge. A somewhat higher proportion of the public (39%) agrees than disagrees (29%) that 'we put too much trust in science'[99]. There is also resistance among young people to the idea that science should be seen as the only valid form of reasoning and the only route to solving human problems. Despite strong belief in the benefits of science and a commitment to logic, half of 11-21 year-olds agree that 'science cannot solve the basic human problems like poverty and unhappiness'. Almost the same proportion claims to learn more about how to deal with life's problems from 'reading fiction, or watching films and drama programmes' as from 'looking for logical explanations'[100].

In fact, it is the young people who are most interested in science and concerned for logic who are often those most sceptical of claims that a scientific worldview that will provide a grand 'fix'[101].

However, the public is no more likely to accept unquestioningly other forms of knowledge in individual and social decision-making. The same proportion of the public agrees as disagrees that 'we depend too much on faith and not enough on science'[102]. Furthermore, the majority of the public disagrees that 'religion should play a bigger role in society'[103].

We therefore see a picture emerging of a public that is able to critically evaluate the usefulness and validity of different forms of knowledge. Where science does not meet people's needs, the public is willing to use other sources of knowledge. For example, there has been a marked increase in the numbers of people who turn to other systems of medicine or to complementary or alternative medicine to replace or supplement their conventional medical advice[104]. In such cases, it is clear that the public is applying different criteria about the validity of knowledge than simply whether it is defined as 'scientific' (see Box 2, below).

Box 2 – Public criteria for judgement of science

Public Criteria Questions	Examples
Does the scientific knowledge work?	Predictions do fail
Do scientific claims pay attention to other available knowledge?	Scientists monitor sheep without paying attention to where they graze, whereas farmers know exactly where they graze
Does scientific practice pay attention to other available knowledge?	When scientists devise and conduct field experiments, which the farmers know will not work
Is the form of the knowledge, as well as the content, recognisable?	Degrees of expressed certainty, standardisation, aggregation
Are scientists open to criticism?	Lack of recognition of other legitimate knowledge and expert actors; Limited admission of errors, omissions, or oversights
What are the social/institutional affiliations of experts?	Imputed social/ political biases and interests; historical track record of trustworthiness, openness
What issue 'overspill' exists in lay experience?	From Chernobyl to Windscale-Sellafield; lack of rational connection for scientists because institutional dimensions defined a priori, but for lay people continuity depends on institutional models of agency and responsibility in decision making and knowledge construction

Based on original source by: Wynne, B. (1992). Misunderstood misunderstanding; social identities and public uptake of science. *Public Understanding of Science 1,* 281-304.

1.7 Defining expertise

While the public may be open-minded about the usefulness of different forms of knowledge, in many cases scientists and policy-makers may be less so.

Research has highlighted the dangers associated with viewing science as the only legitimate form of knowledge or expertise[105]. Brian Wynne, for example, in his study of radiation exposure to sheep from Sellafield, showed that scientists investigating the threat from radiation ignored local sheep farmers' unique knowledge because it was not considered 'scientific'[106]. This resulted in flawed experiments and inaccurate data being collected. Although they were not scientists, the sheep farmers had 'lay expertise' – valuable, specialist knowledge that could help in understanding the problem.

A number of other studies have highlighted the value of 'lay expertise' in understanding environmental, medical and risk-related issues[107]. These studies have drawn attention to the criteria that should be applied in judging the validity of knowledge. Wynne argues for the importance of applying knowledge in a particular context, which narrow definitions of science do not always achieve (see Box 2). Often, communities or individuals with particular experience of such issues have unique knowledge of the issue, of which 'experts' unfamiliar with the particular context may not be aware. This arises because 'scientific culture' emphasises generalising from particular cases to abstract principles and collecting data within laboratories[108]. While there is a tendency to equate 'expertise' with scientific knowledge, expertise in fact emerges with extended experience of any activity or occupation. This expertise should be valued and respected in debates and decision-making.

1.8 Public perception of risks and risk information

As we have already noted, while the public appreciates the benefits associated with scientific developments, there is widespread awareness and concern about the risks associated with these developments. Less than half the British public (43%) agrees that 'the benefits of science are greater than any harmful effects'[109]. Risk perceptions are a central aspect of the public's view of science and technology. Furthermore, one of the most common contexts in which the public receives technical and scientific information or advice is in the communication of risks.

Research shows that there are major differences in how risk 'experts' and the public perceive and define risks. The 'technical' concept of risk is restricted to the probability of an event and the magnitude of specific consequences; in contrast the public's perception of risks is influenced by many other psychological, social and cultural factors[110]. This can result in the public accepting some objects or activities defined by experts as risky (e.g., smoking, car use), and reacting against other objects or activities that are defined officially as low-risk or 'safe' (e.g., MMR, the use of pesticides in food).

Thus, in debates about the acceptability of risk, **numerical measures and official advice may bear little relation to public concerns and responses**. As a result of different understandings of risk, science and society often cross swords over risk issues[111].

The type of risks that the public tend to find more worrying and less acceptable are those that damage identifiable victims, are unfamiliar, inequitably distributed[112] – and above all – are involuntary and out of one's own control[113]. These "fright factors" explain the continued popularity of smoking and driving and in contrast, the high levels of concern around food risks[114]. In addition, people adopt 'shortcuts' in their thinking to evaluate the multitude of risks involved in daily life. These can introduce particular biases in the public's evaluation of risks, distinguishing them from official risk estimates[115]. For example, a common bias in risk judgement is the ***phenomenon of unrealistic optimism***, where people typically under-estimate their chances of experiencing negative events and over-estimate their degree of personal control.

An example is the case of flooding, where only a minority of people at risk from flooding take any preventive action[116]. **People are more likely to take protective action if it *eliminates*, rather than merely reduces, the risk**[117]. Finally, one of the most salient biases in risk perception is known as the '**availability heuristic'**, which refers to how readily a hazard can be recalled or imagined[118]. If a risk event (such as flooding) has occurred in the recent past, it will appear to be a more probable risk[119].

As well as issues arising from how effectively people reason about risks; there is an **increasing acceptance that risk is "socially constructed**"[120]. In other words, how we perceive risk is the product of personal interests, cultural and moral values and social and institutional influences. This range of contextual influences contributes to the variation in people's definition of and response to risks.

In contrast to technical assessments of risks, **the public's risk perceptions incorporate concerns about whether new technologies are necessary or desirable, who will benefit from them, and who may suffer as a result of them.** These are questions of human needs and values, and of equity in relation to the costs and benefits of new developments[121]. What is the 'acceptable' level of risk given the balance of cost and benefit? In the case of mobile phones, most people accept the risk of radiation because they consider it to be outweighed by the benefits of this technology.

Conversely, climate change is considered an unacceptable risk since most people do not feel there are significant benefits associated with it[122]. Furthermore, while people voluntarily accept the risks associated with mobile phones, they do not 'choose' to be affected by climate change in the same way.

Since risks often affect the environment as well as human well being, beliefs and values in relation to nature can influence risk perceptions[123]. People who value a high-growth, technological society are likely to see the benefits of technology as greater than its risks; those who primarily value social equity and environmental quality may consider the risks unacceptable[124].

Similarly, people who believe the environment to be robust and resilient to human actions may find environmental risks more acceptable than those who feel nature is fragile or capricious[125]. This may explain the cultural differences that emerge in perceptions of risk from biotechnologies (discussed in Section 1.9).

With the inequitable distribution of different risks, people's assessment of risks and benefits similarly vary. For those who live near a proposed nuclear development, the perceived costs – for example, in terms of possible health risks, property values, and aesthetic impact – will be greater than for those who live further away. Yet, local residents are likely to be more optimistic about the economic benefits associated with such a development[126]. There is some evidence to suggest that demographic variables, such as gender, age, ethnicity and social grade, affect risk perceptions. Women, in particular, tend to rate risks as more unacceptable than men do[127].

The evidence suggests strongly that **risk perceptions and responses are more likely to be shaped by life experiences than by information campaigns**[128]. Research repeatedly indicates that direct experience is a much more powerful influence than second-hand information on risk perceptions and responses[129]. People trust the evidence of their senses. Air pollution, for example, is detected using visual cues or symptoms of asthma[130]. Where air pollution information or advice conflicts with this sensory evidence and with experience of what coping strategies work, it may be ignored[131].

In accordance with the ***availability heuristic*** (described above) risks that are experienced are typically considered more likely. However, greater fear is often associated with risks which have not been experienced[132]; if a 'risky' but beneficial activity is regularly undertaken without resulting in any harm (as with driving a car), this can serve to reassure people[133]. Proximity to a risk object will also influence risk perceptions and responses. People are more likely to be concerned by local risks than global risks[134] because they pose a more obvious threat to people[135] and because local threats are more likely to have been directly experienced. They are therefore easier to conceptualise and verify than global problems[136]. (However, global problems may seem more serious and worrying because people less able to control them[137]).

Official information about risks is more likely to be relied upon by the public where they have little or no direct experience of the risk object. To be effective, risk communication clearly has to convey information that the audience can understand. Where information is confusing or too technical it will be ignored by the public[138]. However, often, what is labelled public 'ignorance' or 'misunderstanding' in relation to risks is due to the divergence in expert and lay definition of risks resulting in a lack of public resonance with official information and the assumptions underlying it[139]. Often, the public integrates scientific risk information with other forms of knowledge, such as sensory evidence, into 'hybrid' risk conceptions that differ from exclusive scientific definitions[140].

Risk information is actively interpreted in the context of knowledge, values and wider social, cultural, institutional and historical factors, such as public trust in science and scientific procedures, interrelationships with business, civil society and government, and matters of democratic choice, freewill and tolerance of collective decisions[141].

The public judges the **validity of risk information according to how credible and trustworthy they consider the source**. As well as direct experience, informal social networks (such as friends and family) are important and well-trusted sources of information about risks[142]. Where there is a strong sense of local identity, information from people outside the community who do not share the local knowledge and experiences is likely to be viewed with suspicion[143]. In general, information from people with a close relationship or with perceived similarities to the audience will seem to be relevant and credible[144]. For this reason, the media often use members of the public instead of (or as well as) experts as sources in science or risk stories in order to engage people with these stories[145].

As mentioned earlier, scientists are often considered trustworthy, although the public assesses the validity of their knowledge and expertise against particular criteria[146]. Credibility is judged according to scientists' affiliation, track record and perceived competence, objectivity, independence, consistency, and transparency[147].

Media communication can influence the perceived credibility of scientific information. As we discuss in Section 3.2, journalistic conventions can exaggerate scientific controversies[148]. Controversy over risks can exacerbate divergences between expert and public evaluation and erode experts' credibility and confidence in the risk decision process[149]. On the other hand, personal contact with scientists has been shown to be effective in persuading people of the safety of particular risks[150]. In contrast, the credibility and motives of government, industry and media information is increasingly questioned[151].

Closely related to trust in the source of risk information, trust in scientists and regulators to make responsible judgements about the public's safety is also important in the public's risk perceptions. We have seen that there is some concern amongst the public over the effectiveness of science and technology regulation. People tend to find risks that are apparently uncontrollable more unacceptable and worrying[152]. Public trust in experts and regulators further diminishes where risk information does not address broader questions of equity and culpability that concern the public[153]. As we will discuss in Section 8, incorporating lay perspectives in decision-making regarding risks is likely to reduce public alienation from and suspicion of institutions responsible for defining and regulating risks.

1.9 Public attitudes to scientific uncertainty and current controversies

Recent controversies have left their mark on the public's view of science[154]. A survey in 2002 found over half of those questioned (55%) identified a recent controversy that had decreased their trust in research[155]. BSE was mentioned by almost a quarter of respondents, foot and mouth by 17% and GM food by 15%. Cloning/stem cell research, MMR, nuclear issues and climate change were amongst the other issues mentioned.

In many of the above cases, the government has tended to present information as being undisputed, unchanging 'fact'. For example, while government information refers to scientific 'consensus' and the 'facts' of climate change, the public is well aware of the widely reported scientific uncertainty and political disagreement over the issue[156]. **Suppressing uncertainty diminishes public trust and respect[157].** Furthermore, when policy-makers treat 'uncertainty' about technological developments as simply a question of quantifiable risks and exclude broader concerns about unanticipated social consequences, responsibility, institutional trust, and human needs, this is likely to give rise to controversy[158].

Research shows that, contrary to what many science communicators assume, **the public is used to dealing with uncertainty in everyday life**[159]. Also, the public thinks the government should be more open and wants to be given information about risks to enable them to make informed decisions, even where there is uncertainty over the existence or extent of a problem[160]. While the public can accept scientific uncertainty (particularly if they have an understanding of the scientific process), they object to dishonesty, incompetence and inaction on the part of government in relation to potential threats to public health and well-being.

Lessons learnt from BSE and other controversies highlight the importance of honesty and transparency in communicating risks to the public and of listening to public concerns and preferences in determining policy responses. As the Jenkin Report concludes, "admitting to uncertainty does less harm than trying to conceal it", since it prepares the public for a shift in scientific consensus and consequent changes in policy[161].

There are a number of current scientific developments that are generating controversy and anxiety amongst the public. Genetic engineering and biotechnology have received increasing attention by the media[162]. Despite this, most people – 80% in Europe and 70% in the US – feel they are "not very well informed" or "not informed at all" about modern biotechnology[163]. Attitudes towards biotechnology are more negative amongst Europeans (of which the British are typical) than in the United States. For example,

- Only 40% of Europeans believe that GM food is acceptable compared to 60% of Americans
- 60% of Europeans agree that introducing human genes into bacteria to produce medicines or vaccines is acceptable, compared to 75% of Americans.

Optimism about biotechnology is declining:

- In 1999, only 46% of Europeans agreed that 'biotechnology will improve our way of life in the next 20 years'[164].

European reactions against GM have led to cutbacks in biotechnology research funding and warnings by consumer advocacy groups[165].

However, there is not a wholesale rejection of biotechnology; public perceptions vary according to how the technology is applied. Europeans oppose both GM foods and the cloning of animals, but support medical biotechnologies (genetic testing and the production of pharmaceuticals), and environmental biotechnologies (bioremediation). Furthermore, the scope of the intervention – such as whole versus part cloning – is critical in how the public judges the technology. So, whereas cloning of animals for medical purposes is widely rejected, the cloning of human cells and tissues for similar purposes receives moderate support.

The nature of the risk also influences public attitudes to biotechnology. Opposition to GM foods is greater than to GM crops, indicating that Europeans are more concerned about food safety than environmental impacts[166].

These distinctions in the public's attitudes to biotechnology illustrate the point raised in the previous section in relation to risk perception in general – namely, that **the public evaluates scientific developments in light of their perceived risks and benefits**. Benefits are largely equated with perceived usefulness. Information technology and telecommunications, such as the Internet, have very quickly gained public acceptance because the public has experience of these technological developments and finds them useful[167]. The public consistently values scientific developments intended to achieve improvements in health care because of their obvious benefits[168].

At the same time, **risks are perceived in terms of both the nature and immediacy of the hazard, and moral and cultural values**. Accordingly, biotechnologies perceived to have substantial benefits, particularly in healthcare, are supported despite a level of risk. Meanwhile, GM food offers more equivocal benefits and involves unknown risks to the environment and human health and threatens consumer choice. Similarly, cloning animals, while seen as useful, is considered morally unacceptable and resonates with deep-seated cultural fears about 'opening Pandora's Box'. Most Europeans think that this technology should not be encouraged[169]. As Robert Worcester, the Chairman of the research organisation MORI, points out[170], if the benefits are not made clear or are not believed to outweigh the risks, the public is likely to object to these developments.

Attitudes towards biotechnology have been found to vary according to nationality, demographic background and knowledge. Scientific knowledge about genes and genetic technology is higher amongst supporters of biotechnology. In addition, supporters are more likely to be younger, male, better educated and more trusting of government and industry[171]. Acceptance of GM foods is highest in the Netherlands and lowest in Greece; Britain is around the average, although opposition is significantly increasing.

The research suggests that all sections of society (including those who support biotechnology) would oppose the introduction of GM food without labelling and are concerned about whether regulatory system functions adequately in this new area[172]. As indicated in the previous section, institutional, cultural and political context fundamentally influences attitudes to risk.

In relation to other technologies, only nuclear energy scores lower than biotechnology on attitudinal scales:

- 27%of Europeans and 42% of the US public say that nuclear energy would improve our way of life in the next two decades[173].

Other areas of science that involve ethical and social dilemmas include neuroscience, pervasive computing, artificial intelligence and the emerging area of nanotechnology[174]. A recent report by the think-tank DEMOS argues that the scientific establishment needs to engage the public on these issues further "upstream" in the scientific and technological development process in order to avoid undue panic and distrust and avoid past mistakes in communicating controversial science issues[175]. This will be discussed further in Section 8.

2 SCIENTISTS' VIEWS ABOUT PUBLIC ENGAGEMENT

The debate about science communication has tended to focus on public attitudes towards science and scientists, neglecting somewhat the views of scientists. The need for improved relations between scientists and the public, and between scientists and the media has been made clear by research and public discussion. Scientists' perceptions of public opinion about them and their work do not necessarily reflect the public views expressed in surveys.[176]

The lack of knowledge about scientists' attitudes has been addressed by a nationally representative survey of over 1600 scientists, carried out by MORI for the Wellcome Trust in 1999/2000. This examined the attitudes of scientists towards communicating science and considered their role in the public debate.[177] Much of the information in this section is drawn from this report, reflecting the relative lack of literature in this area.

2.1 Scientists' attitudes to public engagement

The MORI survey of scientists aimed to:

- Investigate whether scientists consider themselves to be the people best equipped and most responsible to communicate their research and its implications to the public
- Find out what benefits and barriers scientists see to greater public understanding of science
- Find out what needs to change for scientists to take a greater role in science communication[178]

The results of this survey indicated that scientists have a far more favourable image of themselves than they think the public has of them. It also showed that most scientists are able to see benefits to the non-specialist public having a greater understanding of science. Yet, they also see barriers that prevent public understanding being fostered:

- Three in four scientists regard a lack of public knowledge, education or interest in science as a barrier to public understanding
- One in three view the media as a barrier.[179]

Scientists perceive national newspapers and television as the main sources of information used by the public to gain information about scientific research and its implications.[180] This view reflects public attitudes and represents the consensus opinion.[181] Scientists think that the public primarily trust the media, and those working for charities and campaigning groups, to provide accurate information in these areas, whereas they themselves are most inclined to trust those working in scientific circles.[182] Scientists traditionally have a very negative opinion of the media, believing that journalists portray science in a negative, alarmist way.

Many risk experts (scientists, food producers and public health advisors) regard public concern about food risks as excessive, unwarranted and irrational. This view is sufficiently prevalent to be referred to as a discrepancy between layperson and risk expert, and is often attributed to a 'knowledge deficit' in the lay public. However, as we saw in Section 1.8, psychological and sociological research contradicts this, by indicating that public risk assessment is a complex process, which involves personal value systems being expressed in a situation dependent manner.[183] There is clearly a lack of communication between risk experts and society.

Kathy Sykes, physicist and Professor of Science Communication at the University of Bristol, believes firmly that scientists need to talk more with the public, despite their concerns about having to 'dumb down' their science. She has emphasised the need for public debate about controversial issues, to allow both the public and 'experts' to hear each other's views.[184]

It has been suggested that scientists should pay more attention to the rules and mechanisms of journalism and use aids such as the *Guidelines on Science and Health Communication* published by the Social Issues Research Centre, The Royal Society and The Royal Institution (see Appendix 3).[185]

2.2 Scientists' skills and involvement in science communication

Three quarters of scientists feel 'equipped' to communicate the scientific facts of their research, although only one in five feels 'very well equipped'. Confidence declines when scientists are asked about their feelings towards communicating the social and ethical implications of their research. A survey of those whose research has social and ethical implications showed that 62% feel equipped and only one in ten feels very well equipped. Section 7 addresses the issue of ethics and science in greater detail.[186]

This is a matter of concern given that the majority of scientists believe that it is their duty to communicate their research and its social and ethical implications to peers, policy makers, and to the non-specialist public.[187]

Many scientists feel constrained by the day-to-day requirements of their job, which, they feel, leaves them too little time to communicate their research outside the academic context. Scientists perceive a broad overall audience with which to communicate, but mention a variety of groups as being the most important.

Whilst most scientists feel that scientists should have the main responsibility for communicating the social and ethical implications of scientific research to the non-specialist public, few feel that scientists are the people best equipped to do this.[188]

Just over half the scientists surveyed have participated in a science communication activity. Activities include:

- giving talks to non-specialist audiences (32%)
- speaking to the media (29%)
- participating in open days for the general public at their institutions (24%)
- writing about or publishing their work for non-specialist audiences (13%).

Participation is related to scientists' skill and confidence.

Those who feel equipped to communicate the scientific facts and implications of their research, and those who have received training, are more likely to participate. Also, those who teach as well as conduct research, and therefore have experience of communicating to non-specialists, are more likely to have communicated.[189] Younger and less experienced scientists participate less, with involvement in science communication activities being more common amongst senior academic staff and those on permanent contracts.[190]

One suggestion, put forward by neurophysiologist, Mark Lythgoe, is that scientists may have difficulty with communicating because many have a relative inability to engage with other minds and imaginations *per se*.[191] This is a consequence of scientists typically being *systematic* rather than *empathetic*, a personality trait which makes them good at science but not so good at imagining what is in the minds of the public.

2.3 What has been done to encourage scientists to engage with the public and policy-makers?

A substantial number of scientists have participated in the British Association Media Fellowship scheme, discussed in Section 4.2.2. This suggests that scientists are interested in how their work is communicated, as well as wanting to develop their communication skills. Recent evaluation of the scheme showed that most participants felt that it encouraged involvement in science communication activities by increasing their confidence and helping them to develop the necessary skills.[192] Indeed, a few Media Fellows have pursued a career in science communication, turning their back on research. However, the majority (72%) return to their career as a scientist or engineer.[193]

The Royal Society has been running a Scientist-MP pairing scheme since 2001.[194] Its aims include:

- Informing scientists about how to communicate their work through to parliament
- Giving scientists a perspective of the pressure under which MPs operate
- Giving MPs the opportunity to form links with a network of working scientists
- Giving MPs a better understanding of current science.

Evaluation of this project has shown that feedback on the scheme has been positive with all scientists enjoying the experience and all MPs recommending a colleague to take part. Nine out of ten scientists claimed to have learnt how to contribute directly to the science policy-making process. Nine in ten MPs feel that they gained more awareness of scientific issues and eight in ten increased awareness of the constraints on university research.[195]

2.4 What else can be done to help scientists to engage with non-scientists?

Scientists in the MORI survey suggested a wide range of incentives to improve communication activities. The most commonly mentioned were:

- Incentives from funding authorities to encourage time to be spent on science communication
- Training in dealing with the media
- Encouragement from institutions to spend time on science communication.[196]

Scientists are unfortunately not being encouraged by the terms of reference of the Research Assessment Exercise (RAE) to communicate their science.[197] The Research Councils do, however, expect funding applications to include provision for dissemination of research findings to the wider society, not solely the academic community.

The strategy recommendations from this year's BA Science Communication conference included in their key actions, the need to take steps to reward scientists for engaging with the public. This involved reviewing the impact of the RAE and other ways of assessing performance because of their perceived negative impact on communication.[198] The recommendations also included working with academia and industry to ensure those emerging from undergraduate and postgraduate studies are equipped to play leadership roles and be good communicators.

The overwhelming majority of scientists have received no training to help them to liaise with the media, or to communicate with the non-specialist public. Despite this, most are aware that their institution or department provides a range of communication services, but relatively few are aware of any such services provided by funders.[199]

3 SOURCES OF INFORMATION ABOUT SCIENCE

3.1 From which organisations do people get information?

The two most important sources of information about science for the public are:

- The media
- Formal and informal science education.

These areas will be addressed in Sections 4 and 5 respectively; this section acknowledges the other organisations that provide the public with information about science.

At the 2004 British Association/Royal Society Science Communication Conference, delegates were encouraged to address the issue of access by non-scientists to scientists on a large scale, and how to excite an interest in science amongst the public.[200]

Strategy recommendations included:

- Provision of sufficient funds for large scale engagement activities aimed at groups from all backgrounds
- Rewarding scientists for efforts made to communicate with the public
- Developing new and creative ways of working with the broadcast media to reach and interact with the public.[201]

These general recommendations refer to future plans to expand the current range of sources of information about science. Outlined below are currently existing routes through which information about science can be accessed by the public, and some specific initiatives to improve access.

Libraries are a valuable resource for the public, not only for science information but for other subjects as well. In the US, an initiative called *The Alliance for Innovation in Science and Technology Information* is a partnership among multi-type libraries that support research in science and technology. This is a collaboration for libraries with the aim of increasing resources for researchers and in turn those who read what they write.[202] Increasing access to such resources is clearly a step toward informing the public about new research in science and technology.

Government Information Officers (GIOs) are providers of public information at the central government level.[203] Their roles include:

- Contributing to government policies concerning the public understanding of science
- Raising awareness of the roles of decision makers and purview of state institutions

- Making available information about social services, noteworthy trends and risks to public health and safety
- Monitoring media coverage of public affairs and managing media relations
- Briefing and advising political officials
- Providing information directly to the public
- Sharing information across the administration for the formulation of campaigns and communication.

The regular contributions to public information campaigns, to raise citizens' awareness of social issues and change behaviours, increases the accountability of public officials and helps citizens to formulate their own opinions on issues affecting their lives. The GIO is frequently the first port of call for a journalist and other information seekers.[204]

The Internet is likely to provide an increasing role as a debate space around important social issues. There have been calls for the government to present more relevant webspaces for debating social issues, such as GM technology. Critics of the government's handling of debates, like the *GM Nation?* debate, claim that the government should pay more attention to what is going on on the Internet and act on this.[205] By looking at where public debates are already taking place and who is involved, they stand a better chance of becoming involved. There are calls for the Government to capture and put on display, ongoing social debates, whilst positioning itself in such debates rather than attempting to author its own.[206]

3.2 Trust in sources of scientific information

People place most trust in science which is 'independent'.[207] Whilst more people trust (34%) than distrust (20%) scientists, other groups that may be associated with them are considered significantly less trustworthy. For example, animal welfare groups and industry are greatly more distrusted than trusted.[208] The scientists' workplace clearly has a significant effect on the level of trust that the public has in the scientist. Those who work for tobacco companies are trusted by 18%, whereas those who work in IT are trusted by 68%.[209]

The majority of the public generally trusts scientists to tell the truth:

- When MORI asked respondents to judge the degree to which they trusted particular groups, scientists scored 63% in both 1997 and 1999, and 60% in 2000.

This figure is higher than the public's trust in the average man or woman in the street but far behind doctors, teachers and professors.

As we mentioned in Section 1.3, public trust in scientists is directly linked to the trust in their employers. Accordingly, trust in different types of scientist varies enormously:

- Those working for NGOs such as environmental charities, and medical and mental health charities are trusted the most
- Those working for the tobacco and nuclear industries are trusted the least.[210]

Since the public is sceptical about government and business, scientists' dependence on funding bodies raises questions of maintaining independence, integrity and objectivity when working for interested parties. This poses the question 'Can scientists be trusted to tell the truth about their work, even if it is not in their employer's interest to do so?'[211] This is a problem as it is clear that public distrust is a barrier to the public's willingness to listen to scientific arguments.

The Royal Society's 2004 *Science in Society* Report views trust as pivotal to effectively mediating the relationship between science and society.[212] People are concerned about the applications of science and the speed of development of science and technology, compared with the ability of regulatory bodies to keep up with this.

Numerous guidelines have been produced for scientists to help them talk to the media and to encourage openness, clarity of discussion, more personalised results and use of subtle language.[213] The aim of these is to encourage scientists to appear confident and trustworthy, presenting their work in a way that is easily understood by the public.

Perception of truth is of course influenced by controversies like MMR and BSE, which can make the public wary of any single scientific pronouncement representing authoritative truth.[214] Furthermore, trust in the media is low with the majority of the public saying that they would not trust them[215]. Given that most people get their science and technology information from the media, particularly television, this means that they are inclined to mistrust much that they hear about it.[216]

Media reporting of science can undermine the public's trust in scientific 'experts'. The journalistic convention of 'even-handedness' with regards to science reporting tends to pit spokespeople who represent majority opinions against scientific sceptics, giving the two groups equal weight as experts. One recent study found that even where media coverage indicated that the bulk of the evidence about the MMR jab suggested it was safe, "what people appear to have heard was simply two sides of the debate"[217].

Three-quarters of the British public have no idea what 'peer review in scientific publications' means or cannot define it.[218] Despite this, people clearly want facts to be thoroughly checked before the media are given information about science and technology research. This implies that the public trust scientists and want them to be in charge of checking other scientists' work. There is significant public support for the idea of peer review[219]

It has been suggested that lack of confidence in science and scientists is also due to the way that science educators, for example, teachers, present controversial issues.[220] Although much research is not clear-cut or unquestionably certain, the way in which it is communicated seems to have a strong effect on how trustworthy it is perceived to be. Peer review ensures that research has been subjected to stringent checking by scientists. As we will discuss in Section 4, there is a role for journalists in keeping science 'honest' by questioning research methods and results more. Together, these measures may help prevent the erosion of public trust in science.

4 SCIENCE AND MEDIA

Once people have left school, they get most of their information about science from television and newspapers.[221] A recent survey showed that the public, as well as scientists, believe mass media are the most effective way of engaging the public in science.[222] One in three scientists view the media as a barrier to the public understanding of science, yet 73% consider this to be the most effective method of communicating with the public, and therefore a 'necessary evil'.[223]

It was agreed at the 2004 British Association/Royal Society Science Communication Conference that the media need to figure prominently in a strategy for engaging the public with science because of the major role the media play in informing the public about science issues.[224] The proposed strategies for impact were to encourage working with the media to reach and interact with public at large.[225]

4.1 Science reporting in the media

The media have been identified as an important route through which science communication can occur.[226] Research in the US has shown that newspapers and television are both dominant in providing current knowledge about science. Only amongst college-educated people did magazine usage surpass newspaper usage as a source of scientific information.[227]

When public knowledge derives directly from events that are readily available for people to view, television is the more important source. When events must be reported or interpreted then the advantage is with the print media.[228]

Most science communication providers view the media (press and television especially) as very powerful.[229] Scientific coverage is increasing; broadcasters and publishers perceive a high level of interest among the public and are therefore responding to it.[230] People do stumble upon science topics and issues while reading newspapers and watching television which they may not have otherwise come across.

Although the role played by the media in communicating science is recognised, there remains concern over the accuracy of the information reported about science in the media. Journalists are inevitably blamed for fanciful headlines that sensationalise science. Often, it is scientists who criticise the way the media report their research. The most common complaints concern science being reported inaccurately due to simplification and misinterpretation. As a result, journalists are often held responsible for people assuming that formulated theories and hypotheses are facts.[231]

Analysis of media based 'scare' stories, such as the Swedish acrylamide alarm, show that the way in which science is reported has a big effect on public opinion.[232] Sensationalistic news about biotechnology, for example, is likely to inflame public concerns and reactions to the technology.

News coverage of medical research has incited unjustified fear or optimism in numerous cases. One study analysed science writer's reactions to a *New York Times* medical 'breakthrough' story, which inflated the hopes of cancer patients. More than 60 science writers from the US, Canada and UK were interviewed about the story. Eighty-three per cent of critiques were unfavourable. Science writers were cognizant and concerned about the impact of their work on the public, and accepted the large share of the blame for false hope created by the news coverage of medical research. Their suggestions for improvement were similar to those of the scientific community. Commonality thus exists between scientists and science writers about how to improve media coverage of science issues.[233]

4.1.1 Blaming the scientists for inaccurate science reporting

Scientists are also held accountable for the perceived problems with science reporting. It has been argued that the way in which scientists communicate with the media is a major influence on how their work is portrayed in the media. The Science Media Centre has provided several guides, such as *Communicating Risk in a Sound Bite*, to help scientists communicate effectively with the media.[234]

The reliance of the media upon press releases, which are often written by the scientists, means that journalists with little or no scientific training depend completely on what they are told. The consequence of this is that, in many cases, factual inaccuracies emerge from errors or misleading comments made by the scientists themselves.

The public rely on scientists for objectivity. It is therefore important that scientists articulate clearly when they are expressing opinions and when they are presenting evidence. If a subject area is outside a scientist's expertise they should also acknowledge this. If scientists are misquoted they have responsibility to correct the mistake. The public may be led to believe the claims made by an 'expert', when their expertise might lie in a different field to that which they are asked to comment on.[235] The majority of scientists have not been trained to liaise with the media or communicate with non-specialist public, and as a result their communication skills are not always sufficient.[236]

The role of scientists as the 'experts' is an interesting feature of media reporting. Many scientists criticise the press for its lack of respect for them and their science, but it has also been argued that the press are far too deferential to claims of scientific expertise.[237] The worrying trend in science writing of treating scientists as heroes still appears to exist. Their word is taken as truth and not questioned. Journalists should be quicker to exercise caution and scepticism, and write more about the uncertainty and less about the drama. It has been suggested that journalists have a role in keeping science honest, helping to prevent the erosion of public trust in science.[238]

Surveys of the public's opinion carried out by MORI, indicate that 71% of the public favour replication of results at the kind of level provided by peer review before work goes public[239]. Additionally, fewer than 1 in 10 believe that scientists whose research raises possible concerns about risks to human health and safety should issue those concerns straight to the media before being checked by other scientists. There is an appeal to scientists to talk more about the way science works, with the aim of reducing sensational stories, which generate fear amongst the public.[240]

In several instances scientists have been shown not to be the neutral sources of information that they are often thought to be.[241] Their apparent need for headlines to help generate publicity and to gain funding and recognition for their work, are both factors that may detract from their neutrality when they communicate with the media.

Some scientists have been seen to actively seek favourable press coverage, which promotes public support and therefore is a means of enhancing research support. Public visibility is highly desirable due to scientists' dependence on research grants for the continuation of their work. It appears that there is pressure on some scientists to 'out-extreme' each other to get the headline, and as a result the funding to enable them to continue their research.[242]

Additionally, the financial involvement of many scientists with 'Biotech start ups', and the favourable effect which publicity has upon share prices, adds to the vested interests of scientists. It is hardly surprising that scientific accuracy is sometimes exchanged for sensationalism, if it assures the research will become front-page news.[243]

4.1.2 Blaming the journalists for inaccurate science reporting

Science journalism in the UK is generally praised but unfortunately is seen as insufficiently appreciated[244]. Coverage tends to be considered as less extensive than in other countries, particularly France, Germany and the USA[245]. There are worries that so few science journalists have a scientific background, and fears that this often leads to inaccuracies in reporting. Sometimes journalists are not even sufficiently knowledgeable to ask appropriate questions.[246]

To a certain extent, the constraints of time and budgets on journalists when researching an article help to shape the way in which they report science stories. Another factor is their preoccupation with attracting and holding the attention of the reader, which is best done by taking an angle that will define the science story as 'news'. Therefore, "Emphasis on breaking news is often detrimental to good coverage of science, for important progress may not be associated with striking single events, and significance usually lies in long term consequences".[247]

There is a certain degree of homogeneity in the reporting of science by the media. Often, the same issues are covered, the same sources of information are used and the material is interpreted in a similar way. This can be attributed to the fact that journalists are bound by similar cultural biases, common assumptions about science, and professional constraints.

This has been described as being a frame within which their writing takes place.[248] People have their attention drawn to some issues and perhaps not others, and the media 'frame' discussion by emphasising certain dimensions of an issue whilst downplaying others. However, audiences make active choices about what to read or watch and how to interpret it. As we discussed in Section 1.8, opinion formation is a complex process involving values, beliefs, priorities, concerns, allegiances, associations and patterns of trust.

Scientists and academicians in science writing agree that context and method are important aspects of research to be reported. Science journalists must balance this as they try to simplify complex and potentially confusing findings.[249] A study of the reporting of genomics showed that a research article differed from the popular press in *what* was said rather than *how* it was said. This is surprising given that the primary role of the journalists is to translate science into non-scientific language.[250]

Journalists often ignore previous research and context. There is a need to report the reasoning that backs up findings. It is acknowledged that newspapers must contend with space and reader interest as limitations on what they print. There have been frequent comments on the media's failure to communicate or question the nature of scientific processes even when these processes are central to the issue.[251] News reports often lack information and a suitable level of detail, assume background knowledge that the reader is unlikely to have, and do not supply detail that enables readers to make connections.[252]

The media focus on such examples as controversy around risk related 'cover ups' by government and industry over siting of new facilities.[253] The use of culturally agreed culprits and the 'scapegoating' of particular parties are one aspect of bias that is frequently present in the media. A lack of context, which might help readers to get a sense of importance of the findings, is a problem. 'How this applies to you' and 'What scientists think of this' are two important contexts, which the reader needs to really understand a finding. The following model has been proposed for how the journalist reporting a science story should work:

- Reporter as an intermediary (translation, language)
- Reporter as a watchdog (discuss social and ethical implications, interest in wider picture)
- Reporter as a tool giver (explain science, describe direct context, raise questions of long term significance, give readers the chance to evaluate the issue for themselves).[254]

4.1.3 Fostering understanding between scientists and journalists

Science and journalists represent different cultures, with divergent purposes and conventions. This can result in misunderstanding, lack of mutual respect and difficulties in communication. The press often reports science in an 'ecstatic' manner, which is very positive. This contrasts with the negative and alarmist way in which many scientists believe the press reports science[255]. This is not just a feature of science journalism but also of other forms of popular writing which carry an emotional message to attract attention. It is suggested that scientists should recognise the laws and mechanisms of journalism at work when they read popular science, before criticising how their work is reported.[256]

The media's aim is to amuse and distract us; this is necessary for their survival. The consideration of entertainment, which dominates print and broadcast media, is a major influence on the way science is reported. A survey of 300 US media professionals found that 84% of journalists did not think a story would be covered if it were 'important but dull'. Despite this, science coverage in the media is growing, but is still subjected to journalistic constraints.[257]

Research scientists, who are used to dealing with 'objective reality', are often frustrated by media sensationalism and lack respect for journalists as a result of this. Journalists frequently find scientists incomprehensible and opaque, poor communicators who wrap their message with a layer of caveats[258]. As a result of this they have difficulty getting clear information from them, which is reflected in the quality of their reporting.

Journalists can dramatise conflict by bringing together the many voices involved in an issue. Reporting of science stories often uses quotes from non-scientific individuals, for example, politicians. This gives the message that responsibility for science issues is assigned to socio-political actors even if the information has its origin in a report by a group of researchers. [259] A variety of texts and experts are called upon, and different points of view are reported. This can be confusing for the public who are trying to evaluate the issue. [260]

We can see, then, that the demands of media information and the nature of scientific information collide. They reflect two different ways of representing knowledge:

- Science is an ongoing process data collection and modification of hypotheses; there is no conclusive 'truth' or certainty
- Media representation tends to assume scientists can provide an account that will bring a quick solution to the problem being discussed.

Recognising the different cultural contexts in which scientists and journalists operate is the first step to overcoming barriers to communication.

The BA Media Fellowships offer a good example of how understanding and respect between scientists and journalists might be fostered. The Fellowships place scientists with a media organisation for a short period, in order to:

- Create greater awareness and understanding of the workings of the media among practising engineers and scientists
- Provide active researchers with an insight into the media, which can be employed not only for the individual concerned but also their colleagues. [261]

By encouraging dialogue between at least some scientists and the media, the scheme aims to address the negative views that are often held by scientists about the mass media. A recent evaluation of the scheme indicates that it is achieving its aims: most scientists involved feel it has increased their confidence, provided them with contacts in the media and had a positive effect on their perceptions of the media.[262]

4.1.4. Using the news media for public participation in science

The media contribute to the formation of public opinion, stimulating debate through agenda setting and to some extent steering that debate (through framing and issue definition).[263] The media are therefore well placed to facilitate public debate on important issues because their coverage represents a range of views. Broad airing of views is helpful rather than harmful to national interests; it is a necessary step in the process of forming policy.

Language used by the media, such as 'Frankenfood', can have a significant effect on public opinion. Dominant themes and metaphors recur in reporting, which mean that readers are exposed to a particular view of scientific progress.[264] The media interpret science, and the language they use to portray a story inevitably shapes the image, which is received by readers[265].

However, it is important to recognise that while the media influence public opinion, they do not determine it. The increasingly balanced US media coverage of biotechnology issues, for example, has not produced more negative opinion. [266] Although the media's role in providing information is important there is little evidence to show that people passively receive and act upon such information. For example, in the MMR debate, understanding and beliefs amongst the public were more often influenced by personal contact with health professionals and social networks.[267] This is consistent with the research reviewed in Section 1.8 that highlighted the range of influences on the public's perceptions of science and risk issues. Nelkin suggests that media coverage may draw the public's and policy maker's attention.[268] How such attention will influence public opinion and funding support is less clear.

4.2. Science communication through entertainment media

There is a need to understand the way in which the media influences public opinion in the context of other influences. There is also a need to recognise how the entertainment media conveys information and influences public perceptions. The media do not simply mediate between scientists and laypersons, but are active in the processes of constructing and disseminating science.[269]

Apart from reporting new areas of science and technology, the media offer various opportunities to communicate and teach science to the public. Advertising or drama where science is not the main focus can put across powerful images and stereotypes. Some providers feel that the media, especially television, could be used more and that there are many opportunities for science communication.[270] Science programming to date has been dominated by the drama of the scientific story at the expense of explanation, due to the desire for television as entertainment.

The plurality of digital and multimedia could enable a reorganisation that emphasises understanding, if public service broadcasting is seen as not fulfilling its obligation to broaden understanding in UK. The idea of targeting smaller rather than mass audiences, with resources used at costs corresponding to the audience size, has been suggested. Conversations with scientists, field studies, time-lapsed experiments and web-cams are just a few suggested new ways of imparting science through the media.[271]

Using television programmes like *The Simpsons* and *Star Trek* to teach science is already being piloted in Scottish schools by researchers at the Institute of Science Education in Scotland. The power of showing practical applications of science and the encouragement of discussing topical issues is foreseen as the major benefit.[272]

However, research also highlights the way in which films play on cultural fears about science and stereotypes of scientists. One study, for example, indicated that the most alarming aspects of scientific enquiry depicted in fiction films include: modification of and intervention into human body; violation of human nature; threats to human health by science.[273] There is a very large literature on the portrayal of images of science and scientists in fiction film, which is beyond the scope of this survey[274]. All commentators agree that there is a continual and dialectic interaction between the representation of scientists and their activities – whether portrayed in positive or negative terms – and the public's hopes and anxieties about scientific and technological development. Film drama very effectively communicates ethical messages and cultural narratives; the narrative form can also be used to convey concepts and arguments.

5 SCIENCE EDUCATION

The importance of science is demonstrated by its inclusion as a statutory subject in the core of the National Curriculum for all 5-16 year olds in English maintained schools. However, there are concerns over student's apparent lack of interest in the sciences and criticisms of a curriculum which many feel is too 'content heavy' and unengaging.[275]

There is also widespread concern about the proportion of students choosing science courses at university level, particularly in physical sciences. This trend continues into science careers.

Informal science education is also developing, with numerous projects taking place around the country. These are aimed at both young people and adults, to engage people with science, often encouraging dialogue about contemporary issues rather than sticking only to traditional methods of science education.

5.1 Formal science education

5.1.1 Science teaching in schools and universities

The Jenkin report states that the aims of formal science education are:

- To prepare the most talented pupils [at science subjects] for science at university and beyond
- To develop 'scientific literacy' or 'science for citizenship' for all pupils.[276]

The concept of scientific literacy was discussed briefly in Section 1.5. However, there is concern that the current curriculum is geared only towards those who want to pursue a career in science, neglecting the remainder of students.

Many students appear to lack enthusiasm and engagement with science at school, and feel frustrated by the 'content-heavy' curriculum. The negative effect of course assessment in science, on both pupils and teachers has been highlighted [277]. The lack of opportunity to explore controversy and ethical issues in science is perceived to be a contributing factor, as students may be more interested in these more socially relevant areas.[278] Science teachers have highlighted formal assessment as a major determinant in the level of coverage of social and ethical aspects of science in their teaching.[279]

A recent review of the science curriculum by pupils themselves showed that pupils want the curriculum to include more discussion and practical work in class, as well as focusing more on ethical and controversial issues (see Box 3, below).[280] When questioned about ways of learning, students said that the most effective and enjoyable method was having a discussion or debate in class.

Box 3 – Views of pupils about science in schools

Question	Yes	No	Don't mind
Is it right to include controversial issues such as genetic engineering or cloning in the science syllabus?	69%	1%	29%
Did you struggle with your school science due to a lack of understanding of maths?	21%	79%	-

Source: Cerini, B., Murray, I. & Reiss, M. (2003). *Student Review of the Science Curriculum: Major Findings, Planet Science*, London. URL: http://www.planet-science.com/sciteach/review/Findings.pdf

As we can see from Box 3, the difficulties students face when learning science are not due to a deficit of mathematics knowledge. Rather, the conclusion from the project was that school science fails to convey the ways in which science is relevant to everyday life and affects all of us. Additionally, space should be provided for controversial issues to be included and to allow greater depth of study in topics.[281]

Other research has identified the importance of basing science teaching on student's 'everyday views'.[282] For example, one study of German students aged 15-19, showed that most held an 'everyday' concept of genes as small trait-bearing particles, a notion which could restrict the ability of students to develop an understanding of the scientific explanation. This perspective provides a plausible explanation for the difficulties and misconceptions encountered by students in England learning about genetics. It is suggested that the way pupils are taught should take account of this.[283]

There are calls for GCSEs and A/AS levels to reflect a more flexible and relevant science education for all. The school curriculum does appear to be developing in response to this, with a smaller core being established for Key Stage 4 (14-16 year olds) which will be relevant to students from 2006.

The Nuffield 21st Century Science project, which has already piloted a set of three new GCSEs for 14-16 year olds, aims to present science in a way that gives greater flexibility and genuine choice to cope with students' interests and ambitions.[284] It addresses the need for science, which shapes our lives. The differences between 'science for citizens' and 'science for scientists' are reflected in the syllabus, in which students study:

- The practices which produce science
- Reasoning used to develop a scientific argument
- Issues that arise when science is put to use
- Data and limitations of it
- Correlation and causes
- Theories
- The scientific community
- Risk
- Making decisions about science and technology.[285]

There is also a new AS level in the ethics, history and philosophy of science, for post-16 students. This is due to be piloted in schools from September 2004. Professor Dame Julie Higgins referred to the new AS level, 'Perspectives in science', which was launched last year, in her Presidential address to the BA Festival of Science in 2004. She praised the idea of encouraging discussion of the issues raised by science. It is her belief that if such debate about the social, ethical and political implications of science were to become more common, then more young people might be attracted to study science in sixth form and at university.[286] Attempts to show more of the human face of science are a means of interesting pupils in science, as well as a way to represent **the social context of science** in the school curriculum.[287]

Universities are also starting to take notice of the need for more representation of the social context of science. An example is the 'Study group in Ethics and Medicine' at the universities of Ulm and Marburg who are developing a teaching program in Research Ethics. Comprising small groups and structured case discussions, the courses are not mandatory but the first results were very positive, with high acceptance, high motivation and high demand for further courses.[288] Similar courses are also run at some universities in the UK, such as the University of Bath, which has a mandatory 'History and Philosophy of Science' module on the cross-science Natural Sciences degree.

Many teachers seem to be in agreement with the calls for a revised science curriculum. Most agree that the social and ethical issues surrounding certain areas of science need to be addressed more by the curriculum. A survey showed that 60% of all teachers from all types of institutions and all subjects think there is too little coverage of the issues related to biomedical science.[289] Most teachers want additional resources and exemplification to support them in the teaching of contemporary science.[290] However, the majority of teachers currently feel that their role is to present the 'facts' of their subject and not to deal with any associated ethical and social issues.[291]

The Royal Society's *Genetics Futures* project aimed to address the need for discussion of social implications of science by school children.[292] The Gene Talk, Gene Play and Gene Dreams activities, which comprise the Genetic Futures Project, are aimed at pupils aged 14-16 years. Eight regional schools events took place across the country, with all being heavily oversubscribed for the 80 available places. In total, 800 pupils took part in the event, which encouraged discussion of controversial issues and considering the wider implications of genetics. A strong majority (76%) said they enjoyed the event, learnt from it and had access to equipment, which they usually did not have the chance to use.[293]

Another rationale behind the drive to represent more of the social context of science in the school curriculum relates to the role of scientists. It is felt that scientists will be more relevant, have more impact and be more productive if they can blend outstanding science with communication skills, which can reinforce the important social context of their work.[294]

Research indicates that the skills and qualifications of science teachers are often sub-optimal. The pay differential between teaching and industry for SET graduates is higher than for most other disciplines, leading to a shortage of qualified teachers for these subjects. A survey in the US found that less than 50% of teachers are 'minimally qualified' for teaching maths and science, a trend which reflects the situation in the UK.[295] Yet, those with SET qualifications are likely to be strongly committed to the profession of teaching those subjects.

The foundations of an interest in science are laid at primary school; therefore the role of teachers is crucial. In primary education the likelihood of teachers having a science qualification is significantly less than in secondary education. As a consequence, it is feared that many lack confidence when teaching science.[296] In particular, teachers often lack the confidence, skills and time to manage classroom discussion.[297] A study of the importance of science process skills has revealed the need to connect experiences using a central concept.

Focussing on maths communication and literacy in science based learning, a project called the 'Pre School Pathways to Science' has been designed to help teachers to realise that they can 'do' science, and as a result enable them to teach it better. A more practical, hands-on 'thinking for themselves' approach to science is encouraged.[298] In the UK, there have been suggestions for in-service support of science teachers who often have no science qualifications.[299]

5.1.2 Choosing science subjects at GCSE, Advanced level and at university

In the UK, there is a need to engage girls with SET, encouraging their progression to A level. Girls' attitudes to science are consistently more negative than boys' attitudes. Research shows that girls:

- Like science less than other subjects at school
- Participate in fewer scientific activities
- Have more negative attitudes towards science[300]

A comparative review between 1987 and 1997 showed no change in this trend of gender gap in attitudes.[301] It is also possible that gender differences in science education could be attributed partly to group dynamics and not solely to images of science.[302]

Participation and attainment is broadly equal for boys and girls up to 16 years, but girls tend to opt out of physical science and IT when it becomes optional at 16+. Although girls achieve a higher percentage of A*-C grades in single and double award GCSE science, more boys are entered for single science options, suggesting that girls are not as engaged as boys at a relatively early stage in education. SAT, GCSE and A-level results all indicate girls' ability to achieve in science, when they choose to study it.[303]

Research indicates that the relative lack of girls taking science subjects accounts for the low overall total choosing science subjects. The trend is most apparent in the physical sciences and Information Technology (IT). In the life sciences the opposite effect is found, with girls outnumbering boys.[304]

A survey of Further Education (FE) and Work Based Learning (WBL) in 2002/3 showed that the relative numbers of men and women studying engineering, technology and management were very different. Men outnumbered women significantly with 89,000 men to 2,800 women for WBL, and 96,000 men and 15,200 women in FE.[305] For science and mathematics alone, the figures were 72,600 men to 54,300 women in FE.

There are also gender differences within Higher Education (HE), although increasing numbers of women are entering undergraduate SET programs. The statistics in Box 4 illustrate the trends across the different types of sciences for undergraduates.

Box 4 – Proportion of male and female students taking science subjects full-time at first degree

Subject	Number of women (thousands)	Number of men (thousands)
Medicine	16.9	13.4
Biological science	40.6	23.7
Veterinary science	2.4	0.9
Physical science	16.4	25.7
Mathematics	5.8	9.6
Engineering and technology	11.3	60.3
Total	**486.3**	**429.0**

Source: Equal Opportunities Commission. (2004). Facts about Women and Mean in Great Britain. http://www.eoc.org.uk/cseng/research/facts_about_2004_gb.pdf

Women are clearly under-represented in mathematics, engineering and physical sciences subjects within HE. In 2002/3, only 14% of first year undergraduate engineers were women. Although this is an improvement on previous years, the figures still represent a significant bias in the field favouring men. However, women are in the majority in biological and social sciences, humanities and creative arts.

It is interesting to note the lack of studies which attempt to find out why relatively few men choose to study these subjects.[306] It is also of note that these gender distributions, particularly in the sciences and engineering, do not apply in many other countries.

5.1.3 Science as a career

Encouraging young people to study science is a high priority for the present government. The government has identified a shortfall in the supply of physical scientists, engineers and computer scientists as a problem because of the need to improve support for international competitiveness and economic growth. In particular, the under-representation of women in SET has been described as a waste of a valuable potential resource.[307]

Women are less likely to opt for physical science and engineering subjects at post-16 level, and there are also few females and ethnic minorities who progress to PhD level and beyond in science and engineering fields. Only 13.1% of professors (in all fields) are female and only 3.8% are ethnic minorities.[308] Also, despite women accounting for 60% of UK biological sciences graduates, only 7% of professors in this area are female.

A survey of the 17 US biotechnology companies which comprise the American Stock Exchange Biotech Index, shows women are vastly underrepresented in senior posts: women account for 10% of director positions.[309] The lack of women in the biotechnology industry at the higher levels, is typical of SET industries. This may be due to a high dropout rate, or because the increasing number of female graduates has not had sufficient time to make it to the top of the field yet. Whatever the cause, women still appear to be over represented in the 'underclass' of science, as researchers or fixed-contract employees.[310]

The high dropout rate for women scientists, and the observation that men are promoted more in scientific careers is a problem in terms of efficiency and equity.[311] It is a waste of resources to train women scientists and then see them leave their career prematurely. An additional concern is that women are also paid less than men.[312]

The situation is improving, with women starting to progress to the higher levels within science professions. There are still very few senior managers, with family demands suggested to be a strong influencing factor, as well as 'old boy networks' that favour men who have been in the business longer. Obviously the trend will take time to change so that women are equally represented, but the signs of change are encouraging.[313]

It is important to distinguish between the different types of sciences at this point. A closer look at the statistics shows that women's progress has been further in medicine and biology than in engineering and computer science.[314] These observations reinforce the studies carried out with those considering choosing science subjects at school and university undergraduate age.

5.1.4 Possible reasons for gender and ethnicity differences in science

We have described how women are underrepresented in SET fields at graduate level and in the workplace, where they tend to opt for non-SET occupational sectors (with low pay and poor prospects).[315] There are a number of reasons why women might be opting out of science subjects and SET careers, **but clearly their ability in science is not the cause**. As we have seen, girls perform better than boys at GCSE and in A level subjects and there are increasing numbers of women entering undergraduate SET programmes.

The government's report *Cracking It: Helping women to achieve in SET*, has addressed a number of the factors that affect girls and women's take-up of science:

- The way science is taught
- Preconceptions and stereotypes held by girls and boys and men and women about the nature of work in SET
- The lack of role models for girls
- The negative attitudes in the past of some employers to employing women.[316]

Good teaching is recognised as the most salient factor in the uptake of science by both boys and girls. Strategies include intervening in the curriculum to take account of interests, abilities and preferred learning styles. Attention to environment and resources, making classes more 'girl friendly' (for example, classroom settings in which girls work better without boys), are factors that might improve the current situation. It seems that more girls and women excel in environments that encourage hands-on research, mentoring and co-operation rather than competition. While hands-on activities are considered by teachers to be better than textbooks, there are practical constraints associated with implementing them[317]. The presence and value of role models within education is also important.[318]

Early socialisation is also thought to have a big effect on perceptions of science and technology for girls and boys.[319] It has been widely argued that science is enmeshed with masculine values and the development of scientific knowledge has strong parallels with masculine aspects of psychological development.[320] There is evidence that girls are discouraged by the image of science as male dominated, aggressive and competitive.

It is known that girls often have different value systems to boys and prioritise human, global and environmental issues more highly[321]. Their perception of science as impersonal and claiming to be value-free often alienates them from it and may reduce the interest that women have in it. They tend to prefer creative and socially relevant subjects where there is a degree of involvement through debate[322]. Tailoring science courses to make them more relevant to these needs might be a way to engage more girls with SET.

The predominance of white, male stereotypes, role models, and teachers is considered to be a possible influence the lack of uptake of SET subjects by girls and ethnic minorities. Studies of boys' attitudes to girls in science have shown that negative attitudes exist, compared to girls' attitudes to other girls in science. Lower self-confidence in boys or perceived threat to the male ego may be to blame for this.[323] Intervening early in learning and playing to ensure that development is free from stereotypes may therefore be a way of addressing the imbalance of male-female ratio in SET careers.

A study investigating the differences in racial and gender representation in children's television science programmes found that the stereotypical scientist was not often female or from an ethnic minority background. Television could therefore offer another way of altering the majority view of science and scientists[324]

A study of themes in the content of biographies of women scientists has illustrated certain factors which seem to affect career choices. Parental attitudes, acceptance by male colleagues, family friendly policies at work, personal lives are all factors.[325] A US exploratory study of career decision-making conducted with young women showed that the factors affecting subject choices made are numerous (see Box 5). They include educational policies, levels of financial support, degree of gender equality expected and encountered. Additionally, family members and other role models and educational and work experiences were important influences.

Box 5 – Positive and negative influences on women entering SET careers

Key Factors That Hinder Women Entering Science, Engineering & Technology Studies	Key Factors That Influence Career Decisions
o Scheduling and combining work, study and parenting responsibilities o Unreasonable workloads o Inability to see relevance of extra courses that are not applied to the practical issues (that were the initial attractors to the course) o Large class sizes o Lack of funding o Lack of female role models (although this is a controversial view)	o Family members and friends o People in the field/discipline o Teachers, course experiences and special projects o Work experience o Ability to get a good job/career

Source: Madill, H.M., Ciccocioppo, A-L., Stewin, L.L. Armour, M-A. & Montgomerie, T.C. (2004). The potential to develop a career in science: Young women's issues and their implications for careers guidance initiatives. *International Journal for the Advancement of Counselling, 26* (1), 1-19.

This study also raised questions about whether perceived gender inequity in science affects career decisions. Participants' views were mixed, with many feeling that this was a thing of the past, although some thought it was still present. The effect of having a child is perceived to be negative for employment prospects, with some women afraid to admit plans to marry and have children. Other deterrents to studying science subjects were the lack of apparent application of initial university science topics to everyday life, and the course length. The importance of relationships in career decisions is also evident from this study.[326]

An alternative approach to explaining the lack of women taking SET courses examines whether and how adolescent girls' images of themselves as future scientists change as they move from high school to college. This points to career-related internships and intensive academic programs, particularly those with important mentoring relationships as determining factors. Many girls are interested in prestigious high paying careers during adolescence but change their plans to less prestigious careers later in adolescence.

The perceived conflict between family and career is a major factor in assessing whether it is worth pursuing a career in science. Many women identify balancing family issues as playing an important role in their career decisions[327]. The need for girls to sustain positive views of themselves as future scientists is therefore very important. Appropriate role models can suggest what is really possible, making some careers seem more plausible than others. Therefore, it is suggested that mentoring and career internship programs should be made more available[328]

We noted in 5.1.3 that women are more likely to pursue careers in medicine and biology than in engineering and computer science. Research on the influences of both boys' and girls' decisions to study science at 'A' level and their attitudes to science found that perception of difficulty is a major influence on choice[329]. Attitudes to biology and physics are very different. Perceptions of physics are more negative because the physical sciences are viewed as more difficult. The study found that girls denied they were dissuaded by others from taking science. The difference in attitudes to different types of science subject indicates that it is inappropriate to discuss all sciences together in the context of career decision-making.

Research has shown that those 'outside science' as a profession are not only women, but also racial and sexual minorities and those from deprived areas. This work stresses the need to start from the lives of these groups to democratise science. This requires educating the many people disillusioned and disempowered by formal science education, in an informal and alternative way. Some feminist projects based upon science are already working with women's groups in the community.[330]

In summary, key areas for action are to humanise and personalise science and engineering education and careers and address areas in which people lack confidence.[331]

5.1.5 Current initiatives to encourage take-up of science courses and careers

Efforts to encourage students into science in the UK, particularly into physical science, where they are least represented, are being made by the Institute of Physics (IOP). They offer a £1,000 grant to students beginning physics courses at university to help the decreasing numbers taking such courses.[332] In addition, activities to promote materials science and engineering are aiming to counteract the old stereotype of chemistry and physics as 'boring' and to raise awareness of what materials science involves. The need for teachers to advise students better about subject choices and career progression is clear, and outreach programs, activities and training courses for teachers are required.

Running summer courses at universities for children as a way of promoting informed choice rather than 'hard selling' science is seen to be the best way of doing this. The Centre for Materials Science and Engineering (CSME) at MIT and several English universities have taken the lead in this area.[333] In addition, the new *Planet Science Outreach Programme,* which awards grants to support projects in schools in England that have low levels of achievement in science, has recently been piloted.[334]

A US project which aims to stimulate students' interest in health, science, medicine and research is the Junior Fellows Program (run by the New York Academy of Medicine, New York City public schools and the Regional Academic Medical Centres in collaboration). It fosters the interaction of students and professionals in the urban medical community through seminars, site visits and role model experience. This has proved influential in creating a high level of motivation to pursue careers in health science or medicine, whilst enhancing educational opportunities for urban public school students. There is a special emphasis on improving the proportion of women and ethnic minorities who enter these fields.[335]

The Science Start curriculum in some US pre-schools helps very young children to develop the skills necessary to prepare them for studying science later in their lives. Science content is highly engaging for young children, as they are curious about the world around them. Within this context, they are capable of acquiring a rich knowledge base, which supports the acquisition of vocabulary and the use of higher order cognitive skills such as planning, predicting and drawing inferences.[336]

In the US, the need for more ways to support young scientists in their early careers has been recognised. The long period of training leading to a career in science is a deterring factor to many considering entering the field. The average age of a recipient of a National Institute of Health (NIH) RO1 funding grant is 34, implying that an independent career in science is unlikely to become a reality until this sort of age. So conveying the excitement of science must always be accompanied by the realistic news that individual chances of success are limited. The need for a more 'engaged' mentoring process is suggested as a possible way to tackle the problem of disillusionment with career progression prospects.[337]

More flexible and dynamic schemes for funding are being introduced in Europe, with more support for young scientists to help them to develop independence. The introduction of long-term career development schemes, based on early independence and responsibility for researchers has been put forward. The aim is to provide start up funds for the creation of new research groups in addition to the fellow's grant. In the UK, the Marie Curie Foundation provides grants to help young researchers after their fellowship has finished.[338] It has also been suggested that the UK could learn from the US in offering young scientists a 'road map' to help them develop a vision of their career in science. This would include:

- Interesting university curricula in relevant growth fields
- Research in new areas relevant to economic growth
- Early independence of the researcher.[339]

Encouraging more academic freedom makes extra space for creativity. Reduced teaching, more sabbaticals and flexible 'leaving and coming back' schemes are some ideas put forward. Long-term career prospects are proposed that include:

- Various interesting and different opportunities
- The need in the UK for long term career development schemes
- Career development grants or advanced fellowships.[340]

Although some schemes already exist, for example, Wellcome Trust Fellowships in the UK, there is no overall European unified approach. The US is fortunate to have a much higher research and development budget. As a result, they offer more flexible mobility between areas of research, teaching and curriculum development. This approach could be of benefit to science professions in Europe. Additionally, a proper return mechanism for researchers who want to work in their country of origin is needed.[341]

Every year millions of pounds of high level education are lost to industry, as it is difficult to return to work after a career break. The Daphne Jackson Trust provides two-year half-time fellowships to men and women to encourage them back to work after a career break. These are organised throughout the UK in university and industrial laboratories. They allow outstanding domestic commitments to be fulfilled whilst also assisting with retraining and new research and development. They have been successful in re-establishing careers in academia and industry.[342]

5.1.6 Current initiatives to encourage women into science

Overall, the number and percentage of degrees in sciences awarded to women in the US has increased since 1996. This has been attributed to:

- Establishment and growth of public policies designed and initiated to encourage women to enter graduate studies in science
- Specific unexpected events which bring widespread attention to the accomplishments of women in science
- Financial incentives to encourage the pursuit of science related careers.[343]

There are also initiatives specifically designed to encourage women into SET careers in the UK. One of the key objectives of the **Equal Opportunities Commission** (EOC) is to break down male and female stereotypes. These are currently perceived to limit choice in subject and careers decisions.[344] Despite efforts to reduce the gender gap in employment, very few women are appointed to senior positions.

AWiSE is a multi-disciplinary membership organisation composed of individuals, businesses, associations, institutions and other organisations, all of whom share the common goal of advancing the interests of women in science, engineering and technology (SET).

In response to the report "SET Fair" compiled by Baroness Susan Greenfield, Director of the Royal Institution, the Office of Science and Technology set up the **UK Resource Centre for Women in SET** which aims to establish a dynamic central hub that provides accessible, high quality information and advisory services to employers (including academia and the research councils), professional bodies, Sector Skills Councils, careers professionals and Higher and Further Education to promote best practice in the recruitment, retention and progression of women in SET and the built environment. The Centre which was launched in September 2004 aims to map, coordinate and build on the range of good practice initiatives that have already been developed in the field by providing a strategic focus for driving forward the UK women and SET agenda.

PlanetJemma.com is a website which aims to encourage girls to take an interest in physics. It is interactive science popularisation, launched March 2003, and supported by NESTA and Science Year. Around 31,000 girls logged on in the first 6 months to watch a 14 episode soap opera targeted at 11-18 year old girls with the aim of convincing them that scientists can be 'normal'. By combining entertainment with education, it represents a novel way of engaging girls with physics.[345]

US research has identified the value of interventions developed for talented young women that emphasise enhancing career identity and exploration, building science self-efficacy and self esteem and reducing risk behaviours. It showed that the more girls searched for career information, the more likely they were make non-traditional career choices. Girls' achievement in science at school is overshadowed by the fact that they seem to be less likely to be prepared for college. This, once again, implies that the lack of women in SET careers is a social issue, with self-esteem being a problem as girls underestimate their ability.[346]

5.2 Informal science education and communication

5.2.1 Communicating science through literature and art

It has been suggested that science communicators can learn from research in innovative methods in science education[347]. For example, science can be made more relevant and interesting using narratives. It is possible to convey information accurately, attractively, imaginatively and in a memorable way by using stories, novels, comics and plays.[348] Popular science articles can also make science more accessible to students. They have a useful role in teaching *about* science writing as well as teaching science. They present scientific findings as provisional rather than as fact like textbooks and research articles do. They also help to represent scientists as ordinary people rather than as the 'iconic few' and give an insight into the social construction of knowledge.[349]

The use of performing arts to promote and communicate science has a long tradition and is being further explored.[350] The National Endowment for Science, Technology and the Arts (NESTA) has extensively developed the use of visual arts to raise awareness of science.

The Dana Centre is an extension of the Science Museum in London; it is a venue designed for informal adult education about science.[351] It hosts a wide range of events, which attempt to engage people with science, including through the use of art.[352]

5.2.2 Communicating science via the Internet

'Informal learning' outside the classroom is an important component of both learning about, and positive feelings towards science. Research suggests that informational websites are a source of help for homework and assignments. As a result of this, the possibility of using the Internet to increase science communication to teenagers is now being exploited. The *Ingenious* website, for example, aims to interpret the history of technology and tries to involve users in current scientific debates.[353] The Internet represents an important tool for addressing teenagers' lack of scientific understanding.

Websites are likely to have an important role in creating positive attitudes towards science and even nurturing future scientists. They make active engagement with science possible. Some have argued for an 'alternative Internet' that offers a non-commercial and civic web culture for teens[354]. Teenagers usually go to the web for fun and interaction with others, but also use the web to find information and to learn. The role of teachers as 'gatekeepers' to encourage and facilitate students' use of science websites is therefore important. The knowledge that teenagers perceive the Internet as an easier and quicker method for reference than traditional libraries means that it is a critical avenue for encouraging interest in science.[355]

5.2.3 Science centres and museums

The school science curriculum is seen by many as lacking connection with the applications and social implications of science, conveying a picture as scientific knowledge as a fixed body of certain evidence rather than a continuous process of knowledge creation, and putting insufficient emphasis on contemporary and controversial aspects with immediate relevance to students. Further, there is criticism that most practical work in school science is directed at reaching pre-determined conclusions. This detracts from the association with discovery or technological design. Museums and science centres aim to help citizens to think more independently, critically and creatively than formal education does.[356]

There have been two major developments in the underlying philosophy of science centres and museums, towards creating active learning and involvement. First, the more traditional model of thematic displays is being at very least supplemented by conceptually based installations which focus on developing specific ideas, through activities which lead the visitor to a new level of understanding[357]. "What used to be the trademarks of science centres and science museums – 'wonders of science', 'object displays' and 'curiosity cabinets' are now under scrutiny and critique ....[replaced by] an emphasis on involvement, activity and ideas" [358]. Such activities may be 'hands-on' where the visitor engages with the display without feedback, or 'interactive' which includes both a response and suggestions for further activity [359]. Many British science museums now mix types of display.

It is argued that learning takes place as a consequence of engaging the visitor through recognising the familiar in a new setting, experiencing surprise, and focusing attention through questions. The process of learning is not solely cognitive but includes affect and skills. The experience should challenge beliefs, evoke an emotional and motivational response and promote the confidence and efficacy to explore further [360].

Some proponents argue that the challenges should not only be those which stimulate thinking about the object, but that installations should promote critical thinking in the larger social, cultural and environmental context – for example providing the opportunity for discussion of the implications of (eg) mining development in a hypothetical location, which would draw upon chemistry, geology, the environment, economics and social policy [361]. Such activities are 'critical exhibitions'; "issues-based, inviting visitors to consider socioscientific material from a variety of perspectives, engage in decision-making and healthy debate of complex issues, and critique the nature and practice of science and technology" [362].

Underpinning these developments is a strong commitment to recognising that learning is an active process that takes place in a social context and that, also, opportunity for discussion and small group interaction on site are central to the activity itself. They also recognise that affective responses are of vital importance to effective learning. Such installations therefore lend themselves particularly to school (or similar) parties, requiring also skilled teacher involvement [363].

There remains the problem of evaluating the 'success' of such activities: simple pre- and post-tests of factual knowledge do not capture the spirit of the educational philosophy. A more complex and diverse set of criteria need to be employed, and measures of the various elements developed [364]. Such measures are in process. In one study, the analysis of detailed discourses showed the rich nature of learning, but such methods, while extremely valuable for understanding what is actually going on, are less useful for large-scale evaluation[365].

A number of studies have been conducted on specific effects of science centre and museum experience. Visitor studies at the At-Bristol science centre, which include observing the public and consulting staff, are used to determine the success of their hands-on activities. Findings illustrate how certain attractions are used more by boys and others more by girls, implying gender differences in the perceived attractiveness of different activities. The same is true for age differences. One key finding is that visitors spent more time at an exhibit which explains something that they had already seen.[366]

Other research has assessed the effectiveness of a combined museum and classroom intervention project on science learning in low-income children. The program was shown to support science literacy development with respect to both factual knowledge and concept complexity.[367]

Examples from the US include efforts to promote physics, particularly space science, to both school children and the wider public. The Astronomy/Astrophysics group in the Department of Physics and Astronomy at Louisiana State University has therefore developed an extensive Space Science education and public outreach program. This links up with partners from the state and parish government, the local community, museums and school districts and has influenced classroom facilities and teaching practices. The scientists are helping to train teachers who rarely have a background in space science and physics to educate better.[368] Additionally, The Office for Outer Space Affairs in America has embarked upon a project to enhance the knowledge of the indigenous populations of member States about space science.[369]

The second major shift in emphasis in recent years is reflected in a mission that is shared by science centres. Science centres increasingly see themselves as a hub for dialogue and debate between scientists and the public. They see their role as being able to respond rapidly to new developments in science, which can be achieved by hosting and supporting debates rather than only by creating new exhibitions. The Jenkin Report put science centres in a pivotal position in the science and society debate, and suggested that Foresight panels, research councils and OST should use science centres as a point of consultation and liaison.[370]

5.2.4 Mapping science communication and outreach activities and their impact

Recent research conducted for the Wellcome Trust and the Office of Science and Technology has mapped the range of British science communication activities. Activities included in the mapping project were:

- Public lectures, consultations and conferences
- Advertising campaigns
- Open days and visits
- All science teaching
- Science centres and museums
- Media
- Festivals and roadshows
- Science clubs
- Information leaflets and helplines
- Local community meetings and networks
- Activities for the public in public places
- Theatre
- Science websites
- School lectures, classes and discussions

It was noted that some audiences were under-targeted, for example, female adults. The most successful seemed to be those which encouraged two-way engagement tailored to the specific subject.[371]

The science communicators surveyed for this research identified teaching and media as the most important routes through which to communicate science. Hands-on and interactive methods were seen as best, since they break down barriers between scientists and the public as well as establishing science communication as dialogue.[372]

The research also identified gaps between science education and professional science, because science is moving faster than the communication of ideas can follow. The current school curriculum is good preparation for those who want to pursue a career in science and become scientists, but is less appropriate for those who do not. Another problem – which we noted earlier - is that science is often portrayed as a discipline of absolute certainties. Teachers not only need more time off for science communication training, but also to ensure they use and disseminate the information they are given.[373]

6 SCIENCE POLICY

6.1 Current UK science policy

The present government is clear about the role of science and technology in its economic strategy. Based on evidence of a correlation between economic and scientific wealth[374], the government's new ten-year investment strategy identifies 'high technology and intellectual strength' as crucial to the nation's competitiveness and prosperity[375]. The purpose of its strategy is "to make Britain one of the most competitive locations for science, research and development and for innovation"[376].

Reflecting its commitment to science and technology, the government increased the science budget by 15% in 1998, and since 2000 has increased it by 7% per year in real terms. In 2002, they also introduced a new tax credit for corporate research and development and cash incentives for teachers of science and technology subjects[377].

Most recently, in its ten-year investment strategy, the government has committed to spending an extra £1 billion on science over the period of the next spending review – a real-term increase of 5.8% each year until 2008[378]. This investment will increase core funding of universities, strategic funding for Research Councils and other programs sponsored by the Office of Science and Technology. In addition, the government is aiming to increase the supply of scientists, engineers and technologists by improving and broadening access to science education. As part of its aim to increase the proportion of women in science jobs, it has committed to investing £2.4 million in a new resource centre for women.

However, the Chief Scientific Advisor, Sir David King, has warned that investment in science will only lead to wealth generation if there is knowledge transfer between universities and industry[379]. Following the Lambert Review of 2003[380], which looked at business-university collaboration, the government has included in its investment strategy plans to increase this collaboration in order to see its investment in science exploited for the benefit of the economy. As well as generating national wealth and improving industry and education, UK science policy and spending looks to science for solutions to threats to security, human health and well-being, and the environment[381].

So far, the government claims its increased spending has resulted in a net inflow in 2001 of 5000 scientists and engineers to the UK, a significant increase (70 per year pre-1999 to 199 during 1999-2000) in university spin-off companies, and an increase in patents filed[382].

In addition to funding science and technology that addresses current and ongoing social and political needs, the government's Foresight programme[383], launched in 2002, has funded innovative research that addresses future needs and exploits opportunities in:

- *Flooding and Coastal Defence* to examine increasing threats to the UK from climate change
- *Cognitive Systems*, including advances in computer science, neuroscience, cognitive science, artificial intelligence and their future potential
- *Brain Science, Addiction and Drug Use,* to see how science and technology can increase our understanding of addiction and drug use
- *Exploiting the Electromagnetic Spectrum* to ensure innovation in areas like communications, health and security
- *Cyber Trust and Crime Prevention*, looking at the latest information and communication technologies.

The government has also committed to invest in basic and applied research "that will shape life in the 21st century", namely genomics, bioengineering, e-science, quantum computing, and nanotechnology[384].

Science also plays a central role in international environmental agreements Government policy is to adopt the precautionary principle when there is a risk of serious and irreversible consequences from scientific developments. Related to this, the government advocates admitting scientific uncertainty in its communication with the public in order to foster trust and respect[385].

One of the principal aims of government science policy is to see "confidence and increased awareness across UK society in scientific research and its innovative applications"[386]. In its ten-year investment strategy, it announced the launch of a new grants scheme to promote dialogue and increased expenditure for the Office of Science and Technology 's Science and Society Programme from £4.25 million per year in 2005-06 to over £9 million per year by 2006-07. Aware of previous failures in the communication of science issues, the new investment strategy advocates engagement of the public in debates around science further "upstream" in the scientific and technological development process, for example advocating end-users' involvement in research councils' programmes.

Implicit in the government's encouragement of public engagement in science is engendering public support for scientific and technological developments. Tony Blair in 2002 warned of the dangers that a public opposed to scientific and technological advances, for example in biotechnology, would damage the nation's competitiveness[387]. The increased emphasis in government science policy on public engagement is also consistent with recommendations made by the Jenkin Report[388]. The government's sponsorship of the *GM Nation?* Public consultation was evidence of an increased recognition by policy-makers that public engagement in science issues needs to replace 'deficit' models of science communication.

Delivering on the government's policy requires engendering a cultural change and establishing a strategic framework in which genuine, deliberative involvement of the public in science issues can take place.

The government has defined its role in relation to science as "investor, facilitator and regulator"[389]. As will be discussed in Section 7, the government regulates both scientific practice and the application of science. As well as producing technical standards for products, services and quality management, it has revised its Guidelines on the use of scientific advice in policy-making in order to build public confidence in science[390]. The Guidelines emphasise stakeholder involvement in policy-making and transparency in assessment, management and communication of risk – ensuring early identification of issues and openness about the degree of uncertainty involved in a piece of advice[391]. As the Jenkin Report points out, this represents part of "a considerable change of culture for Whitehall, where advice to Ministers has traditionally been confidential"[392].

6.2 Other perspectives on science policy

6.2.1 The 'knowledge society' as a guiding principle for science policy

In his address to the 8th International Conference of Public Communication of Science and Technology network, Brian Trench considered the role of "the knowledge society" as a guiding concept for public policy.[393] It seems to be generally acknowledged that a 'knowledge-based economy and society' is emerging, not only in the UK, but also throughout Europe.[394] The Department of Trade and Industry's overall aim is "to increase competitiveness and scientific excellence in order to generate higher levels of sustainable growth and productivity in a modern economy".[395]

Trench questions whether this is a threat or an opportunity for science communication. On the positive side, science research and education is higher on political agendas than it ever has been. On the other hand, he argues this may be because technocracy and technological determinism, which underlie the 'knowledge society', are promoting a new social separation of science.[396] The widespread adoption of 'the knowledge society' as a social goal gives high social and political standing to science but simultaneously restricts conceptions of the values and roles of science.

Public policy is acknowledged as the largest single arena for public communication of science, outside education and the media. Trench stresses the need for those in science communication to take more of a role in policy context, rather than leaving it to specialists in policy analysis and social studies of science.[397] This is a sentiment echoed in the Royal Society's 2004 *Science in Society* report. One of their key aims is to "involve society positively in influencing and sharing responsibility for policy on scientific matters".[398]

Two perspectives are taken on policy in this context:

- National government policy on science issues
- The way in which the Royal Society itself develops its policy recommendations on science.

Criticisms of the 'knowledge society' are mainly aimed at the neglect of 'new creative and hybrid forms of knowledge'[399], but also at the assumed relations between educational investment and economic growth which underpin the "knowledge society" ideal.[400]

An alternative to the 'knowledge society' framework for the public discussion of science can be observed when considering sustainable development. Here, science is placed in different social and cultural contexts than those prescribed by the 'knowledge society'.[401] The value of science is associated with its capacity to contribute to world development and quality of life. In order for it to do this it has to join forces with the humanities and social sciences, and take part in any democratic and ethical debate about its purposes and processes.[402]

6.2.2 Issues surrounding science policy

The aim of promoting dialogue 'upstream' in the discovery and development process is to enable scientists and decision-makers to 'sense and respond to public interests and concerns'. When 'downstream' applications and consequences are the subject of debate then dialogue will take place on a wider stage and will integrate with the formal political process.[403] The US is also seeing a demand for greater public participation in the decision-making process with regards to science and technology, in an attempt to move away from the traditional 'trust us, we're experts' relationship between science and society.[404] Section 8 discusses how the current mood for public dialogue in science-related issues relates to the wider political process.

The relationship between science and citizens is moving beyond 'diagnosis' and is now concerned with 'prescription'.[405] However, as we discuss in Section 7, there remains a problem with how to deal with complex ethical and moral concerns, which relate in particular to various forms of biotechnology. It seems that such concerns are not very amenable to consensus solutions.[406]

The current strategy is to view public involvement as complementing both scientific advice and systems of political representation. The Human Genetics Commission (HGC) launched in 2004 a project to examine the ethical, legal, social and economic aspects of developments in human genetics. This will involve consultation with organisations and scientists firstly, with plans to commission a review of research on public attitudes to complement this.[407]

The existing scientific advisory system to policy makers is criticised for its natural inclination to fall back on the style and culture of positivistic science when a problem appears to be complex, such as the BSE crisis. It is also accused of this when there is strong lobbying for a particular course of action that supports a particular interest.[408] A call for recommendations regarding public consultation and involvement, better assessment of scientific advice, and public consultation on policy development has been made in a bid to regain public trust in scientific advice and therefore policy[409].

There is criticism that the underlying science agenda remains closed to public scrutiny, despite increasing efforts to bring the public into discussions about risk.[410] The fear is that the kind of knowledge that the public wants about science is not gathered due to the goal of wealth generation which underlies the UK's science programme. A suggested way of combating this problem is to engage civil society in setting the research agenda, thereby allowing public interest questions to be addressed by the UK science programme.

At present the view is that science institutions enforce a notion of good science which excludes wider questions. The organisation *Scientists for Global Responsibility* suggest setting up a 'Community Research Council', whose funding would only be available for use by public interest groups[411]. This would help ensure science is used to meet social and environmental needs.

There are still problems with the role and status of public input in consultation in the policy making process, within a system which is traditionally predicted on expert advice.[412] An example is the electronic consultation set up for the UK Advisory Committee on Genetic Testing, to assist with its draft code of practise on over-the-counter genetic testing. Despite the general public being encouraged to contribute, media coverage was disappointing and the respondents were all health care professionals. The benefits of an open consultation using the Internet, such as creating awareness in the community of the constraints under which advisory committees work, were not reaped.[413]

Openness about scientific issues is sometimes needed for public action. For example, the Royal Society prepared a document which examined the threat to the UK posed by biological weapons. As well as being aimed at informing policy makers the document was designed to inform the public about the issue in the hope that it would increase public awareness of any threat and the measures in place to counter such a threat.[414]

Scientists could be more effective participants in the political activities in which their work is embedded.[415] The scientific research community itself should play more of a role in and be more competent in developing public policy. For example, calls for more science-based environmental policy in the US have been issued with the assumption that inclusion of scientists and scientific information will improve the quality of complex decisions.[416] However, some ecological scientists were doubtful of their ability to provide scientific answers and as a result were reluctant to engage in decision-making processes. A consensus opinion was that the various groups involved in decision-making should work more closely with each other.[417]

There has been a caution that the level of weight given to science in justifying political agendas is too high. A criticism is that scientific understanding is too often so intrinsically uncertain or diverse enough that it can be used to justify a range of competing political agendas. This use of science, by scientists, to negotiate desirable political outcomes, is perceived as a threat to the development of effective policies in contested issues.[418] By politicising their science, scientists restrict their value and the value of their science.

Finally, the emphasis in government policy on fostering closer links between universities and industry has been criticised by the group *Scientists for Global Responsibility*[419]. They point out that this strategy compromises the independence of scientific research and further undermines public trust in scientists. As we have noted in Sections 1 and 3, the public trust university researchers more than they do researchers working for industry, because they consider universities independent of vested interests. With industry increasingly funding academic research into new technologies like GM crops, "the public is justifiably worried that this is leading to the erosion of academic independence and hence the ability to warn of possible damaging side-effects of these technologies".[420] As that Review argues throughout, fostering public trust in science is key to improving the relationship between science and society.

7 SCIENCE & ETHICS

7.1 Ethics in scientific practice and governance

Conducting scientific research in a professional and ethical manner is the responsibility of individual researchers, their employers, professional associations and research funders. Many ethical issues that arise in conducting research in the life sciences and social sciences are controlled by ethics committees, whose role is to ensure ethical standards and legal requirements are met. There is also a newly published voluntary code of practice for European social researchers based on the principles of upholding scientific standards, compliance with the law, and avoidance of social and personal harm[421].

While such mechanisms prevent research being conducted that does not meet institutional, professional and legal standards of ethics, personal standards and beliefs about appropriate practices may differ – often resulting in emotive debate. As we have seen, ethical concerns are central to the public's views about science.

One of the most ethically sensitive aspects of scientific practice is experimentation involving animals. Public attitudes to animal experimentation depend on the context in which animals are used for scientific research, in particular on the purpose of the research, the type of animal, and the existence of alternatives, such as computer simulations[422]. Regardless of species, there is greater opposition for animal testing for cosmetics than for medical research[423] – 86% of the British disapprove of cosmetics tests involving animal suffering[424]. 68% of the public are also opposed to mice being used to test insecticide safety, if the animals are likely to become ill[425]. More young people (49%) oppose testing on live animals in order to produce nutritionally improved foods, than oppose such research to benefit the environment (35%)[426].

As well as the purpose of animal experiments, the conditions and type of animal also affect their acceptability. If the tests involve no pain for the animal involved, the public favours eight out of nine experiments for mice and seven out of nine for monkeys[427]. Experiments involving cats, dogs and non-human primates are less acceptable to the public, and also psychologically more difficult for scientists to perform, than experiments involving rodents[428].

Overall, the public are mostly (84%) 'conditional acceptors' of animal experimentation – they accept it, so long as it is for medical research into life-threatening diseases only, involves no unnecessary suffering to animals, and there is no alternative[429]. We noted earlier that individuals weigh up the costs and benefits associated with contentious or risky activities in terms of their own values and the perceived usefulness of the research. In the case of animal experimentation, opinions often change once the benefits of research are explained[430].

As with other controversial and risk issues, cultural and demographic variables affect attitudes to animal experimentation. People in Britain are more opposed to animal experimentation than is the US public[431]. Women in particular, and also those living in urban (as opposed to rural) areas, are more opposed to experimentation involving animals[432]. However, reactions to animal experimentation seem to be more driven by ethical and environmental values than by demographics[433].

Licensed animal testing for human medicines is a legal requirement in Britain and most other countries. Animal experimentation in the UK is controlled by the Animal (Scientific Procedures) Act 1986, which restricts the use of animals in research to the minimum necessary and ensures the welfare of the animals used. Underpinning the UK legislation are the principles known as the 'Three Rs':

- *Refining* the procedures so that the degree of suffering is kept to a minimum.
- *Reducing* the number of animals used in research to the minimum required for meaningful results.
- *Replacing* the use of live animals by non-animal alternatives[434].

The Medical Research Council's Centre for Best Practice for Animals in Research aims to develop, disseminate and implement information on best practice in the use and welfare of laboratory animals, and to apply the 'Three R's'. It points to research[435] that "reproducible and accurate data depend on 'healthy and happy' animals"[436].

Although the Royal Society suggest that the UK regulation on the use of animals in research is "the strictest in the world"[437], there is disagreement about whether the current regulations are sufficiently stringent. Many scientific organisations argue that animal experimentation is a vital part of biological and medical science. The Royal Society has warned that "the use of animals in research can never be fully replaced by alternatives"[438].They argue that "virtually every medical achievement in the past century" has been reliant on the use of animals in research[439]. Yet, there are claims that the clinical contribution of animal experiments has not been demonstrated[440].

The recent announcement that the number of animal experiments, particularly involving non-human primates, in the UK has risen to its highest level for 10 years has increased concern about the adequacy of legislation. Some animal welfare groups, such as the RSPCA[441], accept that limited animal experimentation is necessary but are calling for the legal standard in relation to humane animal testing to be raised. Other organisations, such as British Union for the Abolition of Vivisection, have called for animal experimentation to be abolished altogether in favour of modern technology and human clinical tests[442]. In response to animal rights attacks on laboratories and researchers, the government has recently announced that it will be publishing its strategy for tackling animal rights extremism in order to "protect legitimate research activities"[443].

A larger proportion of the public (57%) say they do not trust rules and regulations governing animal experimentation, than say they do (24%).

However, few people claim to know anything about the rules and regulations; over a third say their judgement is based on a lack of knowledge. This suggests an underlying distrust in policy-making bodies irrespective of what regulations are applied[444]. Trust in information about animal experimentation also differs according to the source. Vets are the most trusted source of information whereas industry, manufacturers and pharmaceutical companies are considered the least trustworthy. Government is also not considered a trustworthy source of information[445].

The use of genetic engineering in scientific research is also morally contentious. We pointed out in Section 1.9 that the European public opposes cloning of animals but supports medical research involving genetic testing and cloning human cells and tissues. In recent years, scientists have been able to use genetically modified animals in their research. For example, using transgenic mice, produced to develop neuro-degenerative disease, has resulted in major advances in understanding the human form of the disease[446]. Despite these benefits, such techniques raise ethical concerns about the welfare of the animals involved.

At present in the UK, researchers are permitted, under licence from the Human Fertilisation and Embryology Authority, to obtain stem cells from human embryos that have not developed beyond 14 days. This is only permitted for research into serious disease, such as Alzheimer's, Parkinson's and diabetes[447]. While the public is largely supportive of such research, anti-abortion groups and some religious leaders oppose such research because it results in human embryos being destroyed[448]. Yet, stem cell research could also lead to fewer drug tests on animals and human patients[449].

There is a moral responsibility on scientists to conduct ‘good science’, that is to conduct their research carefully and rigorously, and report their results honestly and responsibly so that they can be understood and used by others[450]. There have been some highly publicised examples of scientists who have fabricated data[451] or communicated misleading, inaccurate or premature results[452]. In the case of the MMR controversy, for example, reporting a correlation between the vaccine and autism in children resulted in many parents rejecting the vaccine. Responsible communication of scientific research is the duty of scientists as well as journalists and other communicators.

The process of peer review serves to encourage honest and rigorous research. The public supports the idea that scientists should replicate and scrutinise each other’s work before they make it public[453]. Transparent and honest communication of research will reduce distrust and suspicion of scientists and the research process.

This communication should also make clear the degree of uncertainty in the results, where results are based only on correlation, and where findings differ from previous studies or mainstream scientific opinion[454]. (The full guidelines for science and health communication, jointly published by the Royal Society, the Royal Institution, and the Social Issues Research Centre, are included in Appendix 3.)

Finally, there are ethical issues relating to the way in which research is funded and governed. Recently, the issue of whether universities should accept funding from 'unethical' organisations was highlighted when the University of Nottingham accepted £3.8m from British American Tobacco to fund a centre on corporate responsibility. It has been argued that doing so may compromise the independence of the research and deepen public suspicion of science, as well as raise the credibility and status of undeserving organisations[455]. Others feel that research quality and public trust are not necessarily compromised by accepting money from such sources. Indeed, doing so allows companies to compensate for past misdeeds and invest in research that will benefit society[456].

Research governance has been central a central issue in this Review. As we mentioned in Section 6.2.2, many would argue that it is ethically beneficial to ensure the end-users and funders of research are fully involved in decision-making about research. As we go on to discuss in Section 8, public participation in science issues should be fostered because it is democratic and because it improves the quality and legitimacy of decision-making[457]. Furthermore, excluding the public from making decisions about risks that will affect them (as a result of publicly funded science and technology) is inequitable and unethical[458].

7.2 Ethics in the application of science

While scientific institutions, funders and scientists themselves may be able to exert a reasonable level of control on the practice of science, once the research is applied it may have considerable unforeseen social and ethical consequences. This raises the question of scientists' responsibility to communicate the ethical implications of their work – to those involved in developing and applying it and to those who may ultimately be affected by it. As we mentioned in Section 2, the vast majority of scientists believe the social and ethical implications of their research should be communicated to peers, policy-makers and the public, although less than half (42%) have engaged in any communication of their research to non-specialists in the last year[459].

The public are far less trusting that scientists will present the ethical and social implications of their research accurately than that they will provide accurate facts: nine out of ten trust university scientists to provide facts, while around half trust them to communicate the ethical and social implications. Yet communicating the ethical and social dimension of research is vital in enabling citizens to make more informed personal decisions and to participate in political debate in relation to scientific developments.

Section 1 discussed a number of ethically contentious scientific developments, such as biotechnology, and how the public perceives these developments. The government's role in ensuring transparent regulation of scientific applications is fundamental in ensuring "consumers are confident that new products are safe"[460]. Where scientific applications involve risks to humans or the environment or conflict with deeply held cultural values or personal morality, the views and responses of public and stakeholder groups should be central in deciding how these developments are applied and regulated. As Dame Julia Higgins recently argued, the degree of public control over how science is used needs to be increased to match its investment and the degree of risk to which it is exposed from scientific and technological developments[461].

There is a diverse range of views about the social and ethical implications of developments in genetic science. The media and public reaction to the cloning of Dolly the sheep clearly demonstrates the cultural fears and ethical dilemma that this technology produces, particularly that it might be applied to clone humans[462]. Similar concerns have been evident in the GM food debate. Opposition to biotechnology includes fears that humans are 'interfering with nature' or 'playing God', and that doing so may lead to unforeseen and uncontrollable consequences for humans and the environment[463]. Proponents of GM crops argue that it offers our only and best hope for feeding the world's growing population[464]. Furthermore, they point out that humans have been effectively 'genetically engineering' nature throughout history by cultivating crops and selectively breeding livestock and pets for particular traits[465].

In the context of human medical applications, the reaction to genetic technologies has generally been less extreme. This is in part because the communication and deliberation processes were better planned, and also because (as we discussed in Section 1) the benefits of these technologies are considered greater. Genetic screening and diagnostic procedures aim to provide information to facilitate informed decision-making. The public largely supports the availability of information about genetic disorders, but opposes the use of genetic techniques to enable parents to choose the sex of their baby[466].

There are concerns that this screening not only sends out particular signals about whether or not certain disabilities and/or genetic disorders are acceptable[467], but also that the techniques might be used in creating 'designer babies'. Furthermore there are fears that this information will be used to discriminate against people with genetic pre-disposition to particular diseases or traits – either by insurance companies or through eugenic policies (such as the UK 'Mental Deficiency Act' of 1913)[468].

Concerns have also been raised that commercial organisations will profit from genetic research by patenting genes. In light of such concerns, the Human Genetics Commission (HGC) is consulting with the public about how the government should respond to developments in genetics and reproduction, with the aim of striking a balance been individual wants and social consequences[469].

Reproductive cloning remains illegal under the Human Reproductive Cloning Act 2001. However, there is concern that restrictive regulation of scientific procedures in this country will not stop controversial research being conducted. Rather it is forcing scientists to conduct their research in countries where regulation does not restrict them, and this country will lose out on valuable and profitable research. Government science policy endeavours to strike a balance between innovation and responsible regulation of scientific and technological developments[470].

We mentioned in Section 1.9, the emerging field of 'nanotechnology' which is beginning to provoke ethical and social concerns about its application and potential unforeseen consequences. Nanotechnology involves working with matter on an ultra-small scale. (One nanometre is one-millionth of a millimetre). The field includes a range of scientific disciplines and potential applications in medicine, physics, engineering and chemistry. Nanotechnology offers huge potential benefits and is already attracting significant investment from governments and industry[471].

There are significant uncertainties relating to how the technology will be used, who will benefit, and about the potential health and environmental risks from nanoparticles. (Some science fiction, for example has raised colourful fears that nanomachines could self-replicate exponentially and devour the planet)[472]. Recently published research has also highlighted the damaging effects on the health of rodents injected with nanomaterials[473].

While the technology is developing very rapidly, ethicists and others have warned that research into the ethical, legal, and social implications is lagging behind[474]. Involving the public in decision-making about nanotechnology early on will avoid undue panic and distrust in this controversial technology.

8 PUBLIC PARTICIPATION & ENGAGEMENT IN SCIENCE

8.1 Democracy and public engagement

There is considerable evidence of the British public's growing political apathy and of alienation from the political process amongst large sections of the public[475]. A recent study, for example, found that over half the public agree that 'what people like me think will make no difference to the Government'[476]. This sense of disempowerment is also evident among young people: less than half (47%) of 11-21 year-olds agree that 'I feel that people like me can make our voices heard if we go about it the right way'.

However, while party commitment and trust in political processes and authority are declining amongst the British public, more varied forms of democracy are emerging[477]. 'Conventional' democratic activities like voting do not necessarily foster public engagement, yet many people are nevertheless morally engaged in ethical, and particularly environmental, issues - many of which relate to scientific and technological developments[478]. Participatory and democratic activities may take the form of consumer behaviour, 'giving' (of time or money to voluntary organisations) as well as more overtly 'political' actions, such as petition signing, campaigning and – increasingly –demonstrating[479]. All of these behaviours indicate commitment to the principles of democracy and political and community engagement and may often appear to participants to be more effective than voting[480].

Motivations for public protest and engagement in particular issues relate to deeply-held cultural beliefs, personal values and the degree to which one identifies oneself as a member of a group or as a holder of particular beliefs. Engagement in controversial science and risk issues also involves balancing perceived benefits and associated costs. Research shows that narrowly defining some issues as 'scientific' without consideration of social and ethical implications is likely further to alienate the non-expert public and prevent their participation in debate and decision-making about science-related issues[481].

Some scientific and technological developments evoke more reaction and protest amongst the public than do others. For example, people are more opposed to the development of nuclear power plants than to new oil wells because they perceive the environmental and health risks associated with nuclear power to be greater than for oil wells[482]. There may also be an association of nuclear power with nuclear weapons, since X-rays, which involve radiation technology with similar risks, are not similarly dreaded[483]. Likewise, there is much greater opposition to the use of animals for testing cosmetics than for medical research[484] and to the use of genetic technology in agriculture than in medical research.

We argued in Section 1 that public reaction to particular technological and scientific developments does not signify an anti-science culture; in fact, people who hold strong ethical views and are more active in their community tend to be more positive about science[485]. Activists and lobby groups who oppose particular scientific or technological developments/ activities often seek out and use scientific information to support their own case. Research highlights the rhetorical uses of science as a means to establish credibility in environmental discourse, for example by environmental lobby groups and conservation organisations[486]. In debating controversial and risky developments, all sides may claim to base their arguments on 'sound science' in an attempt to undermine the validity of other views[487].

People are more concerned about local developments and more responsive to local risks, since they are more likely to pose a direct, tangible threat to individual well being, identity and values. This has been called the 'NIMBY' (Not in My Backyard) phenomenon, in which individuals are only motivated to protest about an issue because it is a direct threat to themselves or their local area. In fact, research has shown that *local* opposition to nuclear developments is not specifically anti-nuclear, but more motivated by factors such as the impact on the visual environment.[488]

Where people opt to form or join activist groups to campaign about an issue (or a range of issues), they may be motivated to do so for different reasons and in expectation of different perceived benefits or outcomes. Studies suggest that 'green' political activists may be motivated by particular social and environmental concerns, out of commitment to religious, political or ethical principles, or from the enjoyment of the challenge and co-operative effort[489].

Regardless of motivation, a sense of personal control and belief in the efficacy of one's actions is crucial in determining whether someone will take action – either on an individual or group basis. In addition, activists are typically less trusting of government[490]. Those who are younger, better educated, on higher income and from high social grades are more likely to feel able to influence the social problems and political processes, while those who feel more insecure in life tend to feel unable to affect change. Ethnicity appears to affect views about government and democracy. Asians are more likely than Afro-Caribbeans and Whites to feel they can influence government [491].

8.2 Principles of public engagement in science

There is an increasing acceptance that science communication should adopt an 'engagement model' – a two-way dialogue between experts and non-experts[492]. This is in contrast to the earlier 'deficit model', in which the benefits of simply providing more scientific information were unquestioned. Scientific knowledge does not predict wholesale support for science or science policy. We know that scientific information is interpreted and used by the public in the context of personal morality and beliefs, cultural values, and institutional relationships. Furthermore, the public not only needs to be informed, it needs to be given *opportunities* to effectively apply their knowledge and preferences in democratic fora[493].

Although some scientists and writers argue that science is 'amoral' and that scientists should communicate evidence and not opinion, this view has been criticised as unrealistic and even dangerous[494]. Science is a human activity and inevitably subject to particular personal, institutional and political interests and values[495]. This is a central assumption of the Jenkin Report:

> "Science is conducted by individuals; as individuals and as a collection of professions, scientists must have morality and values, and must be allowed, indeed expected, to apply them to their work. By declaring the values which underpin their work, and by engaging with the values and attitudes of the public, they are far more likely to command public support"[496].

Asserting that science offers decontextualised, impartial 'truth' about an issue can serve primarily to legitimise the authority of those who claim to represent it and effectively to define other positions as 'wrong'. A broader understanding of how science is really done, and in particular about its inevitable ambiguity and uncertainty, promotes more democratic discussion.

With an increasing acknowledgement of diverse perspectives both within society and involved in the construction and communication of science[497], a democratic, equitable and productive relationship between science and society will embrace the principles of participation and engagement. A number of researchers have argued that public participation in science-related issues legitimises and enriches decision-making processes, by drawing on diverse social and ethical perspectives and local (lay) expertise (described in Section 1)[498].

The reasons for engaging the public in science issues can be summarised as:

- *Normative*: it demonstrates a commitment to democratic principles
- *Instrumental*: it serves particular interests (for example to build trust in policy-makers and scientists)
- *Substantive*: it improves the quality of decision-making and produces socially robust science[499].

The recent report by DEMOS concludes that for benefits on all three levels to be realised "different types of intelligence need to viewed alongside one another, rather than in a hierarchy which places science above the public"[500].

Despite a general acceptance of the benefits of engaging the public in science, the majority of science communication continues to adopt the top-down 'deficit model'[501]. Organisations established to communicate science, including the British Association, the Royal Society, and the Royal Institution, are increasingly focussing their efforts on fostering public engagement and participation in science and science-related issues.

However, their efforts are not representative of the majority of science communication activities in Britain and Europe, which continue to take the traditional form of evening talks or information provided through the media or Internet, with little or no evaluation of their impact[502].

The focus is still mainly on providing information – typically, facts about the science itself. Rarely are ethical, social and political issues raised by science even *communicated* to the public. There is certainly little opportunity for the public to be *involved* in decision-making in relation to these issues. This is partly due to limited funds available for science communication activities[503], but also because those communicating science tend to focus activities around their own interests. A one-way flow of 'science facts' may be of interest to those already involved the topic but will do little to engage anyone else.

Restricting discussion in this way only serves to alienate the public by preventing them from raising broader social concerns about science-related issues. Recent research[504] shows that most people *do* want to have a say in science policy, rather than simply leaving it to the experts. Around half want more influence over the type of scientific research being done, and two-thirds feel that scientists should listen more to what ordinary people think. Over half feel that the funding of scientific research is becoming too commercialised.

Although the public wants a framework within which they can access information about new science and its implications and to be consulted on scientific matters, they have no idea how this might be achieved. They feel their individual opinion would count for little in the context of large organisations that carry out and control science.

Researchers have pointed out that, in contrast to information-based approaches, deliberative and inclusionary measures address perceived social and institutional barriers to democratic involvement and help reduce such feelings of lack of control on the part of citizens[505]. These approaches, which include citizens' juries, round tables and advisory committees, aim not simply to increase understanding but to involve citizens and stakeholders with a diversity of values and opinions in decision-making with regards scientific issues.

Different strategies may be used to achieve public engagement in science issues, depending on the purpose of engagement. At a basic level, 'engagement' may mean education and information provision in the style of traditional science communication. Public engagement has also taken the form of eliciting feedback in relation to specific information or consulting over pre-defined questions. In its fullest sense, public engagement locates the public centrally in the agenda-setting and decision-making processes, and involves innovative and often group-based activities to foster dialogue between stakeholders[506]. According to the DEMOS report[507], this is when we move beyond the deficit model into genuine and meaningful engagement. In the model:

> "It is not up to 'experts' to frame a question and slot in an engagement process to provide the answer. ... Instead, the public should help to decide the questions and the way in which a particular issue will be approached".

Different levels of engagement are likely to be more appropriate at different stages of scientific development - with deliberative public involvement in decision-making ideally taking place further "upstream" in the scientific development process[508].

In planning engagement exercises, other questions that need to be addressed include:

• Is the process intended to include provision and deliberation of information by participants or a 'snapshot' of existing views (which are unlikely to exist in the case of new technologies)?
• Will participants be representative of the population? Is the aim to reach a consensus or simply to explore views?[509]

In many cases, using a combination of approaches will achieve the most effective results[510]. A summary of different forms of engagement strategy and when they are likely to be more appropriate is given in Appendices 4 and 5.

8.3 Past examples of public engagement initiatives

• In 1994, the **Science Museum and the Biotechnology and Biological Sciences Research Council (BBSRC**) organised a consensus conference on plant biotechnology - probably the first British example of "upstream" public engagement. This event involved a panel of non-expert citizens examining and cross-examining the evidence of a range of expert witnesses, before coming to their conclusions[511]. It has been argued, however, that by relying on expert witnesses and focussing the debate about questions of risk, this early attempt at engagement gave lower priority to more diverse forms of public knowledge. As a result it ignored the institutional and policy context, and "fundamental questions around ownership, control and the social ends to which the technology would be directed"[512].

• The **Environment Agency** has also pioneered methods of public participation in risk issues, such as pollution from proposed developments. They have found that public meetings are most effective when they include a diverse range of members of the local community and when sufficient time and information is provided for rigorous and democratic deliberation[513].

• The **Wellcome Trust** has similarly played a prominent role in fostering public engagement in science issues. For example, their *Medicine in Society Programme* aims to stimulate and inform public debate about biomedical science and the related social and ethical issues.

• Recently, the **Wellcome Trust** has also undertaken a 'Deliberative Mapping' exercise to involve various stakeholders in decision-making in relation to transplantation[514]. Where stakeholders have divergent views, methodological tools like Deliberative Mapping can help systematically judge how well different options perform according to particular economic, social, ethical and scientific criteria[515].

• There is also recognition that public engagement in science needs to foster participation in science issues among under-represented and marginalised groups. For example, the *Delivering Inclusion in Science Communication (DISC) Project*[516], which is co-ordinated by the **African-Caribbean Network for Science & Technology and the BA,** aims to enhance participation of ethnic minorities in science communication activities and science issues. This newly launched project is the first of its kind and will involve workshops to elicit the needs, interests and barriers of ethnic minority groups and the development of web-based resources designed to respond to these needs and interests.

• The recent ***GM Nation?*** **public consultation** used a variety of methods, including the Internet, questionnaires and public meetings, to elicit the views of stakeholder groups in relation to GM food. However, this initiative has been criticised for a number of failings, particularly because it took place "too late to influence the direction of GM research, or to alter the institutional commitments of the biotechnology industry and other key players"[517]. There has been scepticism amongst the public[518] and a number of researchers[519] that the exercise merely paid lip-service to the idea of public participation, since it never made clear how the results from the consultation would feed into decision-making. In addition, the debate involved a small and unrepresentative proportion of the lay public. Seven out of ten people had not heard of the debate at all, while a further 15% had heard of it but knew nothing about it[520]. Those who took part were inevitably self-selected and often from organised interest groups[521].

• There have also been a number of more successful attempts at fostering public engagement in science. The **stem cell debate**, for example, took place over an extended period of time and early enough to feed into current legislation on therapeutic cloning. The debate included a range of stakeholders - patient groups, medical research charities, the media and public - who were able to discuss the wider social and ethical consequences of the scientific developments before opinions became entrenched[522]. The gradual introduction of legislation meant, "by the time the stem cell issue became live the ground was well prepared"[523].

• The government's **Foresight project on Cognitive Systems** is another example of successful 'upstream' public engagement in science. The engagement has taken place early on in the development process, as the research agenda is being defined. The Cognitive Systems project involves innovative research in computer science and neuroscience. Research examined whether non-scientists and scientists were able to generate some common language for assessing the new technology. The results showed that both groups "shared the same dreams, hopes and fears for these new technologies" and were therefore able to focus constructive debate around questions such as benefits, concerns and moral issues[524]. The positive results of this exercise indicate that this model could be applied in future engagement exercises.

• As we discussed in Section 5, there are also examples of innovative science communication activities aimed at **women and young people**[525].

8.4 Recommendations for future public engagement in science

We are now in a position to learn from past mistakes and successes in science communication and public engagement activities. We have a much more informed understanding of the relationship between science and society from the wealth of social science research that has been conducted in recent years.

Above all, it is clear that there needs to be a shift to engaging the public in dialogue further "upstream" in the scientific and technological development process[526]. Past mistakes in communicating risky and controversial science issues like agricultural biotechnologies can be avoided by engaging with the public earlier on - "at a stage when it can inform key decisions about their development and before deeply entrenched or polarised positions appear"[527].

This has characterised the more successful scientific debates around human biotechnologies and is the approach recommended in the government's new ten-year strategy for science and innovation[528]. This is also the method being advocated to deal with the emerging and potentially controversial field of nanotechnology[529]. At present, the applications and risks of this technology are not fully known, which presents an opportunity to "intervene and improve the social sensitivity of innovation processes at the design-stage".[530]

The Royal Society's review of the nanotechnology field identifies a lack of research into the social, ethical, health, environmental, safety and regulatory implications of the technologies. A similar review in the US drew the same conclusion. Nanotechnologies hold the potential, for example, for surveillance and military applications and for cognitive and biological 'human enhancement' – all of which raise a number of social and ethical issues.

As with other technologies, questions about who controls the uses of nanotechnologies and who benefits from them will need to be addressed while the technologies are still being developed and before the social impacts are felt. We discussed in Section 7.2 some of the social concerns that have arisen in relation to nanotechnology. In fact, only a minority of the public (29%) have even heard of nanotechnology, and fewer (19%) can give any definition of it. Of those who can offer a definition, only a tiny proportion (4%) feels it would make life worse.

The Royal Society recently ran two deliberative workshops to elicit public attitudes towards nanotechnology. The participants were positive about the potential benefits of the technology but raised concerns about the immediate and long-term effects, reliability and controllability, financial implications, and issues of governance and trust in ensuring the technologies are socially beneficial. Clearly aware of past controversies, participants drew comparisons with biotechnologies and nuclear power.

The Royal Society and others recommend that the future of nanotechnologies be debated now - "at a stage when it can inform key decisions about their development and before deeply entrenched or polarized positions appear"[531].

According to the Royal Society, this debate should be government-funded, and initially focus on governance.

The views of the general public, as well as particular interest groups like the disabled should be elicited and addressed in decision-making. The think-tank DEMOS suggest guidelines on how the public debate on nanotechnologies should be run, drawing on lessons learnt from previous public engagement exercises. These emphasise the importance of transparency, planning, genuine deliberation and feeding the results of the debate into decision-making at both UK and international levels.

These guidelines for conducting the nanotechnology public debate are based on an understanding of the characteristics of successful engagement initiatives in Britain and abroad[532]. The key features of effective public engagement strategies are summarised in Box 6.

Finally, ongoing research should focus on identifying and reducing barriers to public engagement in science. Already, it is clear that there are a number of obstacles to implementing participatory processes. These include the cost and time involved, a potential loss of control over the decision-making process once the public becomes involved, and organised partisans who can dominate discussions[533].

There are specific difficulties involved in adopting the engagement model in the private sector. These difficulties include "low levels of awareness of the need for public engagement and even lower levels of action; … the profit motive; pressures for commercial confidentiality; and tight frameworks of patent and intellectual property law"[534]. It is the private sector, however, which engenders the most public distrust and which therefore, particularly needs to engage with the public.

Box 6 – Key features of effective public engagement strategies

1. Clarity about purpose and outcomes
The process should be well planned, and its purpose clearly defined. There should be transparency about how the outcomes will be used in decision-making.

2. Genuine deliberation - 'upstream' in the development course of new technology
The process should take place early on and allow people to form and revise their views in discussion with others. This means that a range of methods and activities will be required:

- public engagement techniques, including deliberative mapping and citizens' juries, which allow experts and the public to exchange views;
- targeted processes for particular groups, including scientists, social scientists, economists, environment and development NGOs;
- links to wider civil society, for example by encouraging newspapers to involve their readers in the debate, or asking companies with an interest in the technology to involve their consumers;
- targeting under-represented and marginalised groups, such as ethnic minorities, women and young people;
- links to the political process, by asking MPs to debate with constituents, allowing time for debate in Parliament, and ensuring that all ministers (and not just the science minister) discuss the issue;
- a sufficient time period to enable learning and reflection to take place across all of these different activities.

3. Debate informing research as well as policy
The debate process should set the agenda for further research on the social, ethical and environmental dimensions of the science issue. It should be used to inform research priorities, rather than government, scientists or other experts deciding what questions should be answered. In particular, it is important that the process is not unevenly tilted towards narrow framings of risk if these do not accurately reflect public concerns. This is not to say that public views should be privileged over expert views – rather, that the input of expert and public knowledge should inform the way the debate proceeds. It is vital that the link from public engagement to science policy and practices is made clear so that the public can see how their contribution has impacted on decision-making.

4. Virtuous learning circles
Once the debate has taken place, its results must be revisited as technological developments gather pace. Smaller, reconvened dialogues involving people engaged in the original debate could be used to revisit issues and help frame future research. When new regulations are drawn up, it should be clear how these have taken account of the public debate.

5. Institutional and cultural change
The involvement of the public in decision-making about science issues needs to be "over-arching, rather than bolt-on". This demands organisations and individuals commit to institutional and cultural change, towards the integration of public participation in all stages of decision-making around science. Research councils, for example, should ensure the public are involved in setting the funding priorities for research, and that public engagement activities are included in funded research projects. At present, there are few incentives or provisions for scientists to engage in public communication and engagement activities; some may even find it disadvantageous to their career. This institutional and cultural change will involve training to equip those involved with the appropriate skills, and developing in-house expertise in the area of public consultation within scientific institutions.

6. From local and national to European and beyond
The findings of the engagement process should inform the UK's stance in EU and international debates. The UK would then be able to stress that its position on the issue in question is thoroughly grounded in public views. This is important in international forums, such as the World Trade Organization, which currently place far more emphasis on scientific evidence. The UK should also argue for deliberative processes to be embedded in international regulations and decision-making.

Adapted from: Wilsdon, J. & Willis, R. (2004). *See-through Science: Why public engagement needs to move upstream.* London: DEMOS.

APPENDICES

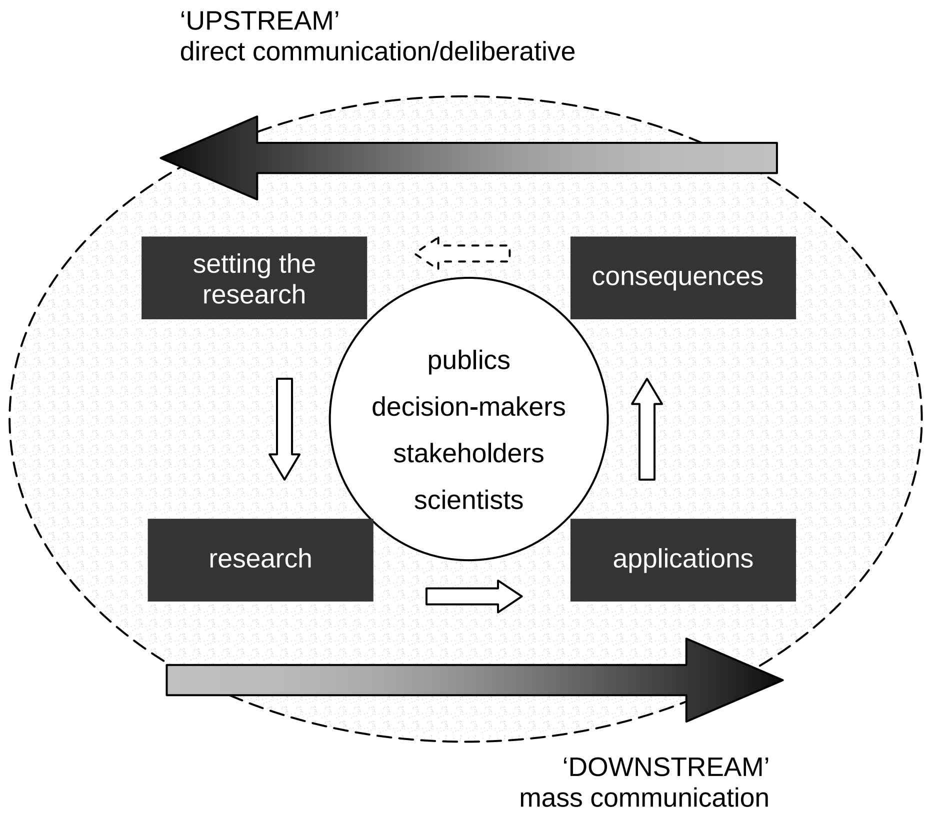
Appendix 1. Methods for public and stakeholder engagement

Source: Davies, G., Burgess, J., Eames, M., Mayer, S., Staley, K., Stirling, A. & Williamson, S. (2003). *Deliberative Mapping: Appraising Options for Addressing 'the Kidney Gap'*. The Wellcome Trust/ UCL/ SPRU/ PSI.

Engagement Strategy	Description	Methods
S1. Education & Information Provision	At distance communication of information and educational material to individual members of the public and stakeholders with no feedback mechanism. Main purpose is to raise awareness and increase understanding. Equally applicable to local through to national scale levels. On its own informing is a form of engagement but not participation. Information provision often provides essential support to other forms of consultation and participation however.	• Leaflets, brochures, information pack, video, newsletters • Exhibitions/displays (non-staffed) • Advertising • Media (TV, Radio, Newspapers) • Internet (information provision)
S2. Consultation (predominantly open to all)	Various approaches to providing information and receiving feedback that are potentially open to all types of participant (i.e. professional and local stakeholders, and the public). Engagement can either be at distance or face-face (with individuals or groups) and tends to be in the form of one-off events or initiatives. Face-to-face approaches are limited to the local scale (but can reach national coverage if repeated), where as at distance approaches can cover all scales from national through to local.	• Site visits • Exhibitions/displays (staffed) • Open House • Public Meeting • Consultation Workshops • Consultation Document • Internet (information/feedback) • Free telephone line (automated or staffed) • Teleconferencing • Public inquiry
S3. Consultation (targeting the public / citizens)	Citizens are targeted through statistically representative samples to take part in quantitative surveys to test 'public opinion', or are recruited to participate in qualitative approaches based on shared demographic features. Quantitative surveys can be at distance allowing wide national coverage, but lack in-depth reasoned responses. In-depth qualitative approaches allow face-face individual or group deliberation and thus tend to be locally situated (but can reach national coverage through multiple processes throughout the country). These methods can be used in front-end framing to benchmark public opinion and underlying values, issues and concerns; or employed to gauge responses to developments or proposals as the decision process evolves. The researcher provides the link to the decision-maker in the form of a report.	• Questionnaire Survey (postal, web) • Telephone Survey • Interview Survey • Focus Groups • Discussion Groups • Deliberative Opinion Poll
S4. Dialogue /deliberation (Groups of predominantly local stakeholders)	Methods that seek to engage local stakeholders, selected to represent the interests of others or as surrogates of the 'general public', over extended periods in group deliberation and dialogue. Participants identify local issues and concerns, set priorities and agree on recommendations for action. Some approaches involve stakeholders in framing and actively engaging in technical-analytic aspects of decision processes (e.g. Joint Fact Finding; Participatory Research), while others involve local stakeholders in the evaluation and prioritisation of policy options. In most cases participants form interactive relationships with decision-makers and specialists.	• Community Advisory Committees (CACs) • Planning for Real • Visioning • Workshops • Stakeholder Dialogue • Joint Fact Finding (and other forms of collaborative analysis) • Stakeholder Decision Analysis • Participatory Research / Participatory Appraisal • Internet Dialogue
S5. Deliberation / Dialogue (Groups of predominantly professional stakeholders)	Approaches that seek to engage (predominantly) professional stakeholders, selected to represent the interests of others, over extended periods in group deliberation and dialogue. The most common approaches for this strategy are Stakeholder Workshops and Stakeholder Dialogue. This strategy also includes approaches that involve stakeholders in framing and actively engaging in technical-analytic aspects of decision processes, and/or the evaluation and prioritisation of policy options. Participants predominantly draw on their own information and specialist knowledges. In most approaches participants form interactive relationships with decision-makers and specialists. This strategy might also include techniques that seek to identify areas of consensus and difference on issues or proposals between groups of professional stakeholders at distance.	• Workshops • Stakeholder Dialogue • Joint Fact Finding (and other forms of collaborative analysis) • Stakeholder Decision Analysis • Multi-criteria mapping • Internet dialogue • Delphi process
S6. Deliberation / Dialogue (Groups of citizens & specialists)	Innovative deliberative approaches that engage citizens, often recruited to be representative of the wider public, in panels over extended periods of responsive information provision, considering issues, and providing recommendations to decision makers. Citizens interact with specialists (or experts) at various points throughout the process – available methods differ in the degree and nature of this interaction and thus the extent of mutual learning and capacity building between panellists and specialists. Some methods have been developed for national level policy, while others are only established at local geographic scales (but have the potential to be scaled up).	• Research Panels • Interactive Panels • Citizens' Juries (Citizens' Panels (Planning Cells, etc.) • Consensus Conference • Deliberative Mapping

Appendix 2. When and how public engagement should take place

Source: Jackson, R., Barbagallo, F. & Haste, H. (2005). Strengths of public dialogue on science-related issues. *Critical Review of International Social and Political Philosophy, 6*.



(The oval represents the social environment within which we live)

Appendix 3. Guidelines on science and health communication

Source: Social Issues Research Centre / Royal Society/ Royal Institution of Great Britain (2001). *Guidelines on Science and Health Communication.* Oxford: Social Issues Research Centre. (Available from: http://www.sirc.org/publik/revised_guidelines.shtml.)

Summary checklist for print and broadcast journalists
1. Credibility of sources • Have the findings been published in a peer-reviewed journal? • Do the researchers have an established track record in the field and are they based at a reputable institution or organisation? • What are the affiliations of the researcher(s)?
2. Procedures and methods • Were the research methods appropriate? • What do other professionals in the field think of the methods?
3. Findings and conclusions • Is this really a 'breakthrough'?
4. The significance of findings • Are the findings preliminary or inconclusive? • Do the findings differ markedly from previous studies? • Do these findings appear to contradict mainstream scientific opinion? • Are these findings based on small or unrepresentative samples? • Do these conclusions generalise to humans from animal studies? • Have the researchers only found a statistical correlation?
5. Communicating risk • Has the risk been expressed in absolute as well as relative terms? • Can the risk be compared with anything else? • Have the researchers been asked 'how safe is it' instead of 'is it safe'?
6. Anticipating the impact • Will the report cause undue anxiety or optimism among audiences or readers? • Have important caveats been prominently included?
7. The role of specialist correspondents and editors • What do specialist journalists think about the report?
8. The role of sub-editors • Is the headline a fair reflection of the report? • Is the caption a fair reflection of the report?
9. Expert contacts • What do other professionals in the field think of the research?

Summary checklist for science and health professionals
1. Dealing with the media • Should I talk to journalists about my work? • Who can give me advice about dealing with the media?
2. Credibility • Have I mentioned whether the study has been published yet in a peer-reviewed journal? • Have I mentioned that the findings are preliminary or a generalisation is not warranted? • Have I mentioned that the results have yet to be replicated? • Have I mentioned that the results differ markedly from those of previous studies? • Have I mentioned that the findings are derived from samples that may be too small or unrepresentative? • Have I mentioned that the findings are based entirely on animal studies? • Have I mentioned that the findings are based on correlation?
3. Accuracy • Have I exaggerated the significance of the findings? • Are there other possible interpretations of the results? • Have I speculated based on opinions or beliefs that are not related to the study itself?
4. Communication of risk and benefits • Have I cited absolute as well as relative risks? • Have I warned of drawing the wrong conclusions about the risk? • Can the risk be compared with anything else? • Could the reporting of my work lead to undue anxiety or optimism among audiences or readers?
5. Is it safe? • Have I explained properly why it is not possible to offer an assurance of absolute safety?
6. Should I complain?

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