Should we be concerned about the public engagement with science?

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I would like to begin my talk by offering you three quotations that, between them, set the context for some of the issues I wish to discuss.

That’s part of the trouble with science. It doesn’t always help… I don’t find it enlightening that the only truthful way of thinking about Herr Schrödinger’s cat is as being simultaneously alive and dead. It may be the only logical way of thinking of it but… the real problem is that I don’t recall asking after the welfare of the cat in the first place.


The message here is: ‘If you’re not interested in the problem, you won’t be interested in the solution’.

This to me remained the greatest of all amazements- how scientists work things out. How does anybody know how much the earth weighs or how old its rocks are or what really is down there in the centre? How can they know when the universe started and what it was like when it did? How do they know what goes on inside an atom? And how… can scientists often seem to know exactly everything but then still not be able to predict an earthquake or even tell us whether we should take an umbrella with us to the races next Wednesday?


This quotation captures something of the wonder and amazement of what scientists are able to do as well as perhaps hinting at some limitations.

It has been said that democracy requires a scientifically literate population. When we consider what this lofty view demands, our hearts might well sink.


This quotation simply reminds us of the challenge facing all those engaged in science education, whether formal or informal.
When historians come to write about science education during the second half of the twentieth century, they are likely to give attention, among much else, to the emergence of the public understanding of science as a field of significant political and educational concern on a global scale. As they do so, they will discover that the field is a somewhat unruly one, rich in acronyms and shifting terminology and replete with beguiling and overlapping slogans capable of sustaining multiple meanings. For UNESCO, the preferred term is scientific literacy, with Member States urged to promote the development of such literacy for all. Scientific literacy is now also the term used to characterise school science curriculum documents from Australia to the United States and assessing such literacy lies at the heart of the science component of the OECD PISA programme, the results of which attract so much press and political attention. But public understanding of science and scientific literacy are only two among many other terms, including the public understanding of research, and a host of more specific literacies such as chemical literacy, biological literacy, technological literacy, computer literacy and, most recently, a term with a rather different connotation, public engagement with science. Rather than attempt to impose any conceptual order on this field, for the purposes of this talk, I shall use the term ‘public engagement with science’, although I shall interpret it very broadly. I shall also make the untested assumption that advancing such engagement is in the wider interests of science itself.

My talk will be divided into three parts. In the first, I will review briefly some of the strategies used to engage the public with science and, where evidence exists, comment briefly upon their effectiveness. In doing so, I shall identify three rather different approaches to understanding the interaction of science with its publics. In the second part of my talk, I want to focus more closely on one of these approaches and, more particularly, on what research can tell us about how lay citizens interact with science and make decisions relating to science-related issues that affect or interest them. As a conclusion, I shall point at some matters that I think deserve more attention than they have so far received.

One of the most obvious current strategies to promote public engagement with science is the development of interactive science centres. Such centres can now be found on very continent, although they bear a variety of names from Techniquest in Cardiff, Questacon in Canberra, Discovery Place in Charlotte, North Carolina and Palais de la découverte in Paris to Science World in Vancouver, Museo Participativo de Ciencias in Buenos Aires to more prosaic titles such as the KwaZuluwazi Science Centre in Durban and The Yokohama Science Centre in Japan. Although the origins of such centres can be traced back to at least the nineteenth century, their more immediate origins lie in the setting up in 1969 of the Exploratorium in San Francisco and the Ontario Science Museum in Canada. Since that date, the number of interactive science centres has increased greatly, especially in the closing decades of the last century and they have come to represent and promote their interests and concerns through a variety of organisations and activities. As an example, an initiative by the Association of Science-Technology Centres (ASTC) and the European Collaborative for Science, Industry and Technology Exhibitions (ECSITE) led in 1996 to the first Science Centre World Congress. The fifth such Congress was held in Toronto in June of this year. Science Centres are now big business, although there are significant differences between them, not least financially and architecturally, and in the
extent to which they have a narrow, rather than a broad, scientific remit, for example by focusing on life or space science. However, all share two characteristics: an emphasis on the contemporary rather than the historic, and the engagement of visitors with science and technology by means of specially designed and constructed interactive devices (Quin1994: 39) How successful these Centres are in achieving their cognitive and affective goals is a matter both of research and contention, as, indeed, are some of goals themselves.

Such centres are part of what is now a substantial industry dedicated to communicating science. As examples, there is a European Science Events Association (EUSCEA), a biennial series of international conferences concerned with the Public Communication of Science and Technology (PCST) and a European Science Communication Network (ESCONET) which has developed training modules in communication as part of an EU funded project.

We should also not overlook the increased and changed nature of the coverage given to science in the print and broadcast media. The generally positive and celebratory tone of the 1950s and early 1960s became much more critical in the following quarter century before giving way to a somewhat more balanced, if at times still suspicious and occasionally bizarre, approach as that century came to its end. During the same fifty or so years, there has also been a shift in coverage away from the physical to the biological sciences, from nuclear technology, through space technology to information technology and currently biotechnology. The notion of risk has risen to prominence, reflecting its salience among scientists, politicians and the public at large. Nor should we forget that today science also features significantly in the so-called blogosphere.

The way in which some science-related issues, most recently BSE, the MMR vaccine and stem cell research, have engaged the attention of the public has prompted a variety of other developments, including reaction from within the scientific community itself. These developments range from Media Fellowships, Science Festivals, SET weeks and the establishment in 2001 of a Science Media Centre within the Royal Institution, to degree courses and modules in science communication, leaflets and training courses to help scientists present their findings to a lay public, a Sciencewise Expert Resource centre, the Beacons for Public Engagement, and a range of prizes for outstanding print or broadcast journalism. The extent and nature of the shift that has taken place within the scientific community in the last two decades or so should not be underestimated. No longer do most scientists look at involvement in the popularization and communication of science as something that could damage their career: today, such activities amount to something of a commandment.

This growth in interest in engaging science with the wider public is equally clear in the rapid increase in number of books that might be categorised as popular science, now often a distinct section in any large bookshop. Stephen Hawking’s *Brief History of Time*, published in 1988 was a publishing phenomenon, although he was not the first to contribute to the genre. To this could be added the books by many other authors, scientists and non-scientists, including Peter Atkins, Paul Davies, Leon Lederman, Steve
Weinberg, Lewis Wolpert, Richard Dawkins, Carl Sagan, Patrick Moore and Richard Feynman who, between them cover most aspects of contemporary science. There is even a web site devoted exclusively to popular science books (www.popularscience.co.uk) and annual prizes are awarded by The Royal Society for the best publications. Children are well catered for, books being supplemented by a range of CD-ROMs and DVDs, many of which are of a very high quality.

To these substantial elements of informal science education, we should add the formal component provided at schools, colleges and universities. Science now occupies an established place in school curricula at both primary and secondary level in countries throughout the world, although such a place has not been achieved without a long struggle, and the manner in which science has eventually been accommodated differs from one education system to another. In England, science has been a compulsory component of the national curriculum since 1989. All pupils must now study science between the ages of 5 and 16 and what they are required to know, understand and be able to do is enshrined in law. To put the matter simply: in England, as elsewhere, more science is now being taught to more children than at any time in history. More pupils are also achieving some form of qualification in science. In 2008, over half a million candidates entered for the new science qualification at GCSE level, of whom 12.4% were awarded an A* or A grade. Over 430,000 entered for Additional Science, with 15.2% gaining the same two highest grades. Beyond compulsory schooling, it is a somewhat different story, with the numbers of entries for A-level physics in particular regarded as a source of concern. It should be noted, however, that the relative unpopularity of the physical sciences as subjects of advanced study is not unique to the United Kingdom but is found in many other developed countries that might be roughly grouped as belonging to the Western industrialized world.

As a result of the kinds of activities to which I have referred, we are confronted with something approaching a paradox (Pickstone 2000). On the one hand, the general public is probably now better informed about science, technology and medicine than at any point in history (MacDonald 2008). On the other, this growth in popular interest and the expanded provision of information about science, technology and medicine have been accompanied by increasingly strident expressions of concern about the level and nature of scientific understanding among the lay public. Moreover, at a time when people in general have never been healthier and are living longer than ever before, we live in a culture that is astonishingly averse to risk, including, but no means confined to, those risks associated with scientific or technological developments.

What can we say, therefore, about the effectiveness of the many attempts to engage the public with science?

The earliest attempts to investigate the public engagement with science were directed at how much science people knew, the first of the three approaches that I want to say something about. These attempts were quantitative and relied on a range of direct questions such as ‘Does the earth go round the sun or the sun round the earth?’ or ‘Electrons are smaller than atoms: true or false?’ The limitations of such questions, both
technical and conceptual, are obvious. Simple guessing provides a 50% chance of securing a correct answer and questions of this type are not always as straightforward as they appear, at least to those required to respond to them. Consider the question of whether or not the Earth is round. A well informed respondent might wonder whether an oblate spheroid can properly be called round. Others might have a view of the Earth as indeed round but also as flat like a pancake, a view that some children certainly hold (Vosniadou and Brewer 1992).

Of course, not all the questions in surveys of this kind are of this type. As an example of a different kind of question, consider the following.

Two scientists want to know if a certain drug is effective against high blood pressure. The first scientist wants to give the drug to 1,000 people with high blood pressure and see how many of them experience lower blood pressure level. The second scientist wants to give the drug to 500 people with high blood pressure and not give the drug to another 500 people with high blood pressure, and see how many in both groups experience lower blood pressure levels. Which is the better way to test this drug?

<table>
<thead>
<tr>
<th>Year of survey</th>
<th>2001</th>
<th>2004</th>
<th>2006</th>
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<tbody>
<tr>
<td>Per cent correct</td>
<td></td>
<td></td>
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<tr>
<td>Male</td>
<td>39</td>
<td>49</td>
<td>42</td>
</tr>
<tr>
<td>Female</td>
<td>38</td>
<td>43</td>
<td>41</td>
</tr>
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Only 42% of respondents to this question chose the second strategy, although this seems significantly better than the 26% who got it right when the question was first asked in 1995.

As measures of how well the public understands science, all these questions are obviously limited, but they are not without some value. The data are often available over time so that it becomes possible to identify any significant changes or trends and they do offer a somewhat depressing glimpse of how far elementary scientific knowledge is diffused within the public at large. The biennial surveys conducted by the National Science Board in the USA constitute perhaps the best known measure of this kind, but broadly comparable or overlapping surveys are undertaken elsewhere, for example, in the European Union, in China, Japan, India, Korea and Malaysia, and to these can be added a number other surveys relating to more specific scientific issues such as stem cell research, evolution and nanotechnology. The methods of data collection used in these surveys range from computer-assisted random telephone dialing to face-to-face interviews, and there are substantial differences in the sample sizes. Commonly, the surveys also probe attitudes as well as knowledge, and some also attempt to explore how well the respondents understand the way in which science works. Most results show little overall change over time, although the responses to individual items shows some variation and some of the responses can only be regarded as disappointing. Thus, in 2006, (n = 1,864) only 53% of those sampled by the National Science Board in the USA replied that electrons are smaller than atoms and only 55% knew that the earth takes one
year to travel around the sun, although the answers to most other questions of this kind were more encouraging. Most of you here will be familiar with results of this kind so I will not dwell on the findings, although I can show you some data from the Eurobarometer survey of Europeans, Science and Technology carried out between January and February 2005.

<table>
<thead>
<tr>
<th>Item</th>
<th>True %</th>
<th>False %</th>
<th>DK/NA %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The sun goes around the earth</td>
<td>29</td>
<td>66</td>
<td>4</td>
</tr>
<tr>
<td>2. The centre of the Earth is very hot</td>
<td>86</td>
<td>7</td>
<td>7</td>
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<tr>
<td>3. The oxygen we breathe comes from plants</td>
<td>82</td>
<td>14</td>
<td>4</td>
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<tr>
<td>4. Radioactive milk can be made safe by boiling it</td>
<td>10</td>
<td>75</td>
<td>15</td>
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<tr>
<td>5. Electrons are smaller than atoms</td>
<td>46</td>
<td>29</td>
<td>25</td>
</tr>
<tr>
<td>6. The continents on which we live have been moving for millions of years and will continue to move in the future</td>
<td>87</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>7. It is the mother’s genes that decide whether the baby is a boy or girl</td>
<td>20</td>
<td>64</td>
<td>16</td>
</tr>
<tr>
<td>8. The earliest humans lived at the same time as the dinosaurs</td>
<td>23</td>
<td>66</td>
<td>11</td>
</tr>
<tr>
<td>9. Antibiotics kill viruses as well as bacteria</td>
<td>43</td>
<td>46</td>
<td>11</td>
</tr>
<tr>
<td>10. Lasers work by focusing sound waves</td>
<td>26</td>
<td>47</td>
<td>28</td>
</tr>
<tr>
<td>11. All radioactivity is man made</td>
<td>27</td>
<td>59</td>
<td>14</td>
</tr>
<tr>
<td>12. Human beings, as we know them today, developed from earlier species of animals</td>
<td>70</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>13. It takes one month for the Earth to go around the sun</td>
<td>17</td>
<td>66</td>
<td>16</td>
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</tbody>
</table>
Perhaps somewhat surprisingly, the results of this survey led those responsible for it to conclude that ‘Europeans have a good knowledge of scientific topics’ (European Commission 2005: 40), a conclusion that might be thought somewhat optimistic, although the European Commission makes clear that this is the view of the authors and not necessarily of the Commission itself. It is also a conclusion that also masks significant differences between European countries.

Since many of the questions are common to surveys used in several countries some degree of international comparison is possible, subject always to the limitations of cross-national work of this kind (Shorrock-Taylor and Jenkins 2000) and the fact that the different surveys are conducted at different times. Broadly speaking, the USA and the countries of the European Union are in line as far as the direct tests of scientific knowledge are concerned, although there are differences on individual items, most notably on the question which asks whether human beings have developed from earlier species of animals. There are also differences in public attitudes towards science and technology. For example, a much higher proportion of Americans than of Europeans, Russians or Japanese believe that the benefits of scientific research outweigh any harmful consequences. However, support for basic research in science is strong in all the countries surveyed and there is a high opinion of science as an occupation.

Clearly, much more is involved in understanding the public engagement with science than surveying how much science people know. A second, and very different, approach seeks to establish the mental models that people invoke when they explain natural phenomena. When asked whether or not all radioactivity is man-made, what model of radioactivity does the respondent have in mind and how does this model, this schema, influence the answer that might be given? What model of electricity underpins an understanding of what it means to earth an electric circuit? How is the transfer of heat conceptualized? Is everyday motion explained in Newtonian or Aristotelian terms, the latter we should note having so far held sway far longer than the former?

Understanding mental models such as these and developing strategies for changing them are of enormous importance in science education, both formal and informal, since there is ample evidence that what might be called everyday, common sense, understandings are very resistant to change, partly because in some instances, such understandings serve their purpose adequately. That, of course, is why they have survived so long in human history and one of the reasons why a modern scientific understanding of everyday natural phenomena took so long to develop. These everyday common sense understandings of scientific phenomena, variously referred to as alternative conceptions, preconceptions, student conceptions or misconceptions, have received attention from researchers for over a generation, although the focus has overwhelmingly been on those of school age, rather than on adults. There are now data relating to young people’s common sense understanding of a wide range of topics from chemical change, light and evolution to geological time, force and air pressure, the most recent bibliography (Duit 2007) covering the field listing 7,700 research papers. The work has also embraced the concepts that science teachers have of scientific phenomena, a field that has an added importance when such teachers cannot be assumed to have a thorough grasp of the topics they are required
to teach, as is the case with most primary school science teachers and their secondary school counterparts teaching outside the science specialism in which they are formally qualified. Despite all this work, far too little is known about the interaction of the various mental models, and agreement about the best way to effect conceptual change is limited.

From this perspective of mental modeling, advancing the public engagement with science requires the supplanting of a scientifically incorrect understanding by a more orthodox mental model and the building of interconnections between the various models that relate to a range of phenomena. Establishing and developing these interconnections constitutes scientific understanding and generates the structure that substantiates a scientific discipline.

However, this approach embodies an assumption that is open to some question, namely that a correct scientific understanding of a phenomenon, however desirable in itself, is always necessary in order to function effectively when dealing with a problem that has a scientific dimension. Consider the case of a group of assembly workers in a computer company who are chained to their benches by an earthed metal bracelet in order to prevent damage to sensitive electrical components by the build up of static electricity. Research has shown that despite being surrounded by advanced solid state technology, these workers regarded electricity as a fluid which can flow, pile up (as static electricity) or be discharged to the earth, envisaged as a large container within which electricity is dispersed or lost. This ‘unscientific’ model of electricity enabled the operatives both to function safely and to make sensible decisions when confronted with problems. Likewise, it is usually more convenient, and adequate, for heating engineers to think of heat as something which ‘flows’ rather than in terms of the kinetic theory of matter. Such scientifically incorrect understandings should not be dismissed lightly as misconceptions or misunderstandings. They have often been well-tested in the context of experience and action, and, in those contexts, have served people well. When we seek to remedy these unscientific ideas, as in school science teaching, we would do well to recognise that the tenacity with which they are held probably owes less to cognitive ability than to the proven usefulness of scientifically wrong ideas in the world of everyday experience. It is also important to acknowledge that the commitment of experts to promoting understanding, and that of citizens to acquiring knowledge upon which to ground action, can be very different. In some contexts, scientific explanations are simply unnecessarily sophisticated and over-elaborate for the purposes in hand. This, of course, is not to prioritise, in some general way, everyday understanding over scientific knowledge. While such understanding may be adequate in many contexts, it can in some circumstances be misleading or even dangerous.

I turn now, therefore, to the third approach to understanding the public engagement with science, an approach that might be called social or contextual. Before turning to a more contemporary example, I will try to illustrate aspects of this approach by drawing upon Ibsen’s play, *An Enemy of the People*, written as long ago as 1882. The play illustrates, among much else, what happens when an attempt is made to ground action on scientific knowledge without due regard for the wider context within which that action is to take place. In the play, Dr Thomas Stockman discovers that the public water supply in the
village where he has come to live is contaminated. Expecting to gain some recognition for his well-grounded scientific discovery, he finds instead that he becomes, as the title of the play indicates, an enemy of the people. In part, this comes about because his discovery threatens to destroy the town’s reputation as a spa, although it should be added that Ibsen characterises him as opinionated, vain and stubborn. It is possible to interpret the play in terms of scientific truth being set aside or over-ruled in favour of a coalition of financial, medical, political and corporate interests. However, more is involved here. The audience knows that the water supply is contaminated and much in the play subsequently turns on the failure of the doctor to understand and accept that the solution to the problem he has identified is not uniquely scientific. The risks to the spa of acting to remedy the contamination are social, economic and medical and any solution to the problem requires, not just science, but also consideration and negotiation relating to these other, non-scientific, issues. In other words, in the everyday world, scientific knowledge is not seen as standing independently, and certainly not as a discrete measurable entity as Eurobarometer and similar surveys might suggest.

The play also offers an astonishingly early insight into some of the ways in which scientific knowledge can be called into question. Anyone who followed the prolonged battle in the USA in the 1970s between the Environmental Protection Agency and the oil industry over the risks associated with lead in petrol will recognize the parallels with the following dialogue, taken from the play, between the doctor, Stockmann, and his wife’s foster father, Kiil, who owns the tannery that turns out to be responsible for the contamination of the water supply. Kiil is thus understandably anxious to protect both his reputation and his business interests. He steers the dialogue towards such issues as sampling, causality, methodology and the limits of scientific certainty.

**Kiil:** How do you know that on the day you made your tests, there wasn’t something unusual about the water? …How do you know the rest of it wasn’t pure?

**Doctor:** It’s not probable. People were getting sick last summer…

**Kiil:** They were sick when they came here or they wouldn’t have come!

**Doctor:** Not intestinal diseases, skin diseases…

**Kiil:** …Maybe the food was bad. Did you ever think of the food?

**Doctor:** No, I didn’t look into the food…

**Kiil:** …Admit it!… You have some doubt.

**Doctor:** Well, there’s always a possibility… Nothing is a hundred per cent on this earth but…

**Kiil:** Then you have a perfect right to doubt the other way! You have a scientific right!
Let me turn now to another, much more recent and actual, rather than fictional, illustration of this contextual approach to understanding how the public engages with science: the controversy over the combined measles, mumps and rubella vaccine (MMR). The controversy was triggered by the work of Dr. Andrew Wakefield which, it was claimed, pointed to a causal link between the vaccine and autism. The research evidence against such a causal link is overwhelming but a concerted effort among health care practitioners, policy makers nationally and the World Health Organization clearly failed to convince significant numbers of parents of the safety of the triple vaccine. The result in the United Kingdom was a decline in the rate of immunisation at first dose from a peak of 92% in 1995 to 84% in 2001-02, with the average at second dose standing at 74%. What was going on here? In what way, or ways, were the parents simply failing to engage with the science, if that was indeed the case? Were the media, or some sections of the media, reporting the issues inaccurately or irresponsibly? Were the strategies adopted by policy makers and health care practitioners inappropriate or simply ineffective?

Research can give us answers to at least some of these questions. One study suggested that parents can be roughly divided into three categories: the immunisers who might opt for complete (i.e. both doses of the vaccine) or incomplete vaccination (i.e., first dose only) and the non-immunisers who declined to have their children vaccinated at all. Those parents who declined vaccination in whole or in part were mainly those who had seen children with autism or believed, correctly or not, their own child to be autistic. Set against autism, measles, mumps and rubella were judged to be relatively mild, treatable and even natural.

I think there can be positive things about them catching measles, mumps and rubella. They’re not as serious as the government makes out…If children get measles, mumps and rubella, it helps build up their natural immunity, and that’s better than the immunity built up by vaccines (parent, 1st dose only).

Conversely, those parents who agreed to immunize their children were far more likely to have experienced, or observed in relation to their immediate family, the negative impact of measles, mumps or rubella.

Measles, mumps and rubella inoculation is very important to me. My husband had a brother who died when he was 1 year old with measles encephalitis, and I think one of the big problems is [parents] don’t realize how serious measles is and can be as a disease. (parent, complete vaccinator)

Without going into further detail, the key point here is that many parental assessments of the impact of disease and of the associated risk of vaccination were influenced, even determined, by their direct or vicarious experience, and not simply by the repeated assurance of medical experts or the overwhelming scientific evidence about the safety of the vaccine. The comment of one parent in the sample of 65 mothers studied who worked as a health care practitioner is of particular interest. She commented that at some level it ‘sounds awful’ to be reliant on scientific information: it is as if, as a mother, she felt she should somehow know best for her children.
However, more is involved than experience, direct or otherwise. General practitioners, the media, friends and family all played their part in shaping individual decisions and in a variety of ways. Here, for example, is one parent’s view of advice from her GP.

My problem with the advice coming from the GP is that I know that GP practices are paid a bonus for having so many patients vaccinated, so how can their advice be impartial? They’re running a business at the end of the day.

(Parent, non vaccinator)

Here is another.

I’ve never had a problem with doctors not being willing to listen to my viewpoint, but I know that doctors and health professionals have to toe the government line, so I am not expecting an unbiased discussion.

(Parent, non-vaccinator)

This, of course, raises an important question about where, and by whom, such a discussion might be initiated.

The parents also had views about the kind of advice given to them by government and health agencies about the MMR vaccine. NHS leaflets were seen as dull and uninformative, especially when set alongside the photographs and punchy headlines of the mass media. In broad terms, they simply weren’t hard hitting enough and didn’t illustrate either with figures or photographs what the consequences of failing to vaccinate might be.

The MMR case highlights a number of key issues, notably those of trust, communication, risk and the need to understand the complex processes, both technical and social, by which scientific knowledge comes to be established and accepted by the relevant scientific community. It also highlights the need for a better understanding of the decision making process itself, a matter to which I shall return briefly towards the end of my talk.

Another set of issues is illustrated by some work that my colleagues and I at Leeds undertook a few years ago of how elderly people, living on low and fixed incomes, managed their domestic energy budgets, i.e., kept warm and ensured they fed themselves adequately within the resources available to them (Layton et al. 1993). The study showed that they did so in ways that are much more subtle and complex than might be understood, or even dictated by, a consideration of the nature of energy itself. The scientific advice about conserving energy while keeping warm and healthy, was readily available from charities, local and central government. That advice was clear, unambiguous and eminently sensible: insulate the loft and cavity walls, double glaze all windows and doors, move to a smaller house, keep bedroom curtains closed to retain heat, use a specially marked thermometer to warn of the risk of hypothermia, and so on. Yet all of the elderly people interviewed in our study, many of them in their ‘80s, had
good reasons for not doing these things, although they were well aware of them. Investing in insulation was regarded as not producing a sufficient return on capital outlay by those who judged that they had managed well enough thus far and may not live much longer. Moving to a smaller house might be discounted since it involved moving away from friends, family or neighbours. One elderly lady even told us that if, as advised, she kept her bedroom curtains closed during the day in order to retain heat, her neighbours might think she was dead! As for the thermometer, the blue warning zone was frequently disregarded because it didn’t correspond with personal judgements of how cold the individual actually felt, one lady telling us that if she ‘took any notice of that thing’, she’d be ‘roasting’! It is clear, therefore, that for these elderly people, the purchase, consumption and use of energy had personal and social dimensions as well as economic and scientific.

MMR and the management of a domestic energy budget are but two of many examples that might be given of the ways in which people engage with science within the context of their everyday lives. The context may be that of employment, leisure, the home or the family, and the focus of concern may be essentially personal, political, economic or social. The associated scientific issues can be equally diverse, ranging, for example, over health care, food safety, diet, nuclear power, climate change, mobile telephone masts or stem cell research. This diversity is itself significant since there are important differences between the various sciences: conceptual, linguistic, methodological, philosophical and in the immediacy of the bearing that they have upon everyday life and thought. There is perhaps a case for being less concerned at ignorance of the relative size of an electron and an atom than at a failure to understand that antibiotics do not kill viruses or that there is no evidence to support the efficacy of homeopathy, a practice that needs to be distinguished from herbal medicine.

Nor can we think in terms of a homogenous public. The public can be segmented in many ways, e.g., by age, gender, interest, employment, income, political or religious beliefs, and most of these are not discrete categories. Any account of the engagement of the public with science, or perhaps one should say the sciences, is therefore complex and contingent. Generalization is thus almost inevitably misleading and needs to be treated with caution. Nonetheless, subject to that caution, we can perhaps offer the following broad observations.

- The engagement of adults with science is differentiated by science, social group (including age and level of education), and gender and is often linked to decision-making or action.
- Adults choose a level of explanation they judge adequate for the purpose in hand.
- The engagement of adults with science is rarely simply on scientific terms: scientific knowledge is considered alongside other knowledge and understanding available to them, together with their social and institutional connections. If adults choose to ignore scientific knowledge, this does not necessarily mean a failure to engage with science.
- Adults have complex attitudes towards the risks associated with science-based developments.
What, therefore, should be the focus of our concern about the public engagement with science? Clearly, ignorance of elementary scientific knowledge or a failure to use correct conceptual models in explaining everyday phenomena can be regarded as disappointing and, in some circumstances, is dangerous. However, I believe the greater problem lies in a failure to understand how scientific understanding is generated, validated and accepted, a failure that allows junk science, from astrology to scientology, to flourish, although other factors are, of course, involved. Beyond this, there is Isaac Asimov’s claim that if scientists are not understood, they will be persecuted; sadly, recent attacks on some of those researching in the life sciences suggest that such a claim is not without foundation.

Science assumes that the objects, processes and properties of the natural world are independent of us and our beliefs about them, and science seeks to give a reliable and universal explanation of them based upon the testing of empirical claims. In the so-called post-modern world of the 21st century, the core beliefs and values that have traditionally underpinned science have all been challenged. The challenges have been diverse, from the epistemological to the political. They have come from philosophers, sociologists, feminist scholars, environmentalists, cultural relativists and they have flourished at a time when science has become an integral feature of industry, the military and society more generally. There have, of course, been vigorous responses to these various challenges, those of Sokal (1996 and 2008; Sokal and Bricmont 1998), Gross and Levitt being perhaps the most familiar (Gross and Levitt 1994; Gross, Levitt and Lewis 1996). Even so, however much I personally side with those who reject the radical claims of the social constructivists of knowledge, I am forced to recognize that we live in a world in which celebrity endorsement, personal conviction, subjective belief and irrationality indicate a worrying degree of disengagement with science in many different parts of the world, including our own. That disengagement takes a variety of forms, from pseudo-sciences like astrology and the paranormal, to the absurdities of crystal healing and the scientism that deploys scientific models in wholly inappropriate fields.

Let me give you just a few examples of what I mean. Madonna has claimed to be neutralizing the radioactivity around Chernobyl with Kabbalah fluid, whatever that is, and she and Demi Moore are introducing Kabbalah ideas into elementary education. London hosts a Kabbalah centre that is actively promoting ‘Spirituality for Kids’, and Kabbalah-derived curricula can be found in schools in the USA, the UK, Israel, Malawi and some of the countries of Latin America. Does this matter? It does when, in the words of one of its leading advocates, ‘[Kabbalah] is not a religion, it’s a science. It’s the science of connection’ (Bartlett 2008:9).

The astrological interests of the Reagan White House have been well documented. According to the presidential aide, Donald Regan, ‘virtually every major move and decision the Reagans made during [his] time as White House Chief of Staff was cleared in advance with a woman in San Francisco who drew up horoscopes to make certain the planets were in a favourable alignment for the enterprise’. President Reagan was, of course, only one among many prominent figures who, throughout history, have been drawn to predicting the future on the basis of imaginary planetary influences. They include Catherine de Medici, Napoleon, Charles de Gaulle, François Mitterand, Adolf
Hitler and Leonid Brezhnev. When the Burmese generals decided to move the capital from Rangoon they did so because an astrologer had warned that an impending catastrophe could only be averted by moving the seat of government. The same astrologer asserted that the most auspicious time for the relocation was 6.37 a.m. on November 6th 2005 and that was when the move duly took place.

Nearer in time and place, Cherie Blair found her religious beliefs no obstacle to wearing a ‘magic pendant’, known as a Bio-electric shield and composed of ‘specially cut quartz crystals’, that cocooned her with energy to ward off evil forces. She also invited a feng shui expert to rearrange the furniture in Downing Street, employed a ‘life style guru’ and had her swollen ankles treated by a ‘dowsing healer’. The treatment involved swinging a crystal pendulum over the affected area and feeding the Prime Minister’s wife strawberry leaves grown within the ‘electromagnetic field’ of a Neolithic circle he had built in his back garden (Wheen 2004: 130).

Failure to understand how science achieves its goals also helps to sustain the hijacking of science in support of a variety of non-scientific causes. In India, Meera Nanda has described the growing rejection of scientific reason by right wing Hindu fundamentalists. It is a rejection promoted by reference to the cultural or mental imperialism allegedly represented by the science of the West but which, at fundamental level, is an attempt to reassert a religious hegemony over all aspects of life and thought. The parallel with other religions and cultures is clear. So, too, are the tensions that stem from the attempts to legitimate scientific beliefs and attitudes in societies, cultures or social groups which have not shared in the values associated with the European Enlightenment (Nanda 2003; Hongladarom 2006).

History tells us that the assimilation of such beliefs into a political philosophy or religious movement is likely to be disastrous. Think not simply of historical examples such as Nazi Germany or Stalin’s Russia but, of contemporary Protestant fundamentalism and its creationist, anti-evolutionary beliefs in the United States of America. Think, too, of the way in which science was called into service as auxiliary scripture in the nineteenth century and compare that with what some are advocating today. The first quotation comes from an object lesson on ‘scriptural natural history’ of the 1840s in which the teacher has led the children through a simplified account of the extraction of silver from its ore.

Teacher: ‘Tell me two things about which the refiner is careful’.

Class: ‘He is careful not to take the silver out of the fire till it is pure; and he is careful not to keep it there when it is pure’.

T: ‘And how does he know?’

C: ‘When it is pure it reflects his image.’
T: Now, dear children, I have given you this lesson on refining silver, to lead you to understand what Jesus Christ does for us. Listen to this passage of scripture. Speaking of the Lord Jesus Christ, it says,’ He shall sit as a refiner and purifier of silver, and he shall purify his people, and purge them as gold and silver, that they may offer to the Lord an offering in righteousness…’

Is this essentially different from the following, taken from a Christian website over 150 years later? The reference is to emperor penguins, huddling together to survive the harsh climatic conditions in which they live.

While the fathers are caring for their unhatched chicks and braving the harshest of weather, they all huddle together in a huge heap for warmth. The ones on the outside rotate, so they all have a turn in the middle. *Philippians* 2:2-4’: Then make my joy complete by being like-minded, having the same love, being one in spirit and purpose. Do nothing out of selfish ambition or vain conceit, but in humility consider others better than yourselves. Each of you should look not only to your own interests, but also to the interests of others.’

In each case, it is scripture, in these examples Christian scripture, that has primacy, not science. Science is ideologised by a world view that that is considered superior to the view of the scientific community. Such a stance ultimately requires that scientific theories and concepts are evaluated in accordance with basic principles of an over-riding ideology.

As Gerald Holton has observed, counter science movements of various kinds are not new. Writing in 1993, he concluded his book *Science and Anti-Science* with these words.

…it is prudent to regard the committed and politically ambitious parts of the anti-science phenomenon as a reminder of the Beast that slumbers below. When it awakes, as it has again and again over the past few centuries, and as it undoubtedly will again some day, it will make its true power known (Holton 1993: 184).

As long as science is invoked for corrupt purposes, whether these be religious or political, the need for vigilance will remain.

What, therefore might be done to challenge the pseudo-sciences and try to at least delay the appearance of Holton’s beast?

Education is perhaps the obvious first port of call and the incorporation of science into the national curriculum has been an important step forward, although it is not without problems and any benefits are likely to be in the longer than the immediate term. Ever since that curriculum was introduced, it has required the explicit teaching of something of the nature of science. It is not, I think, a harsh judgement to say that this component of
the national curriculum has presented science teachers with severe, and initially at least, insuperable difficulties, difficulties that required several subsequent revisions to transform the ‘Exploration of Science’ and ‘The Nature of Science’ in the original statutory Order, first into ‘Scientific Investigation’ and, from 2008, into ‘How Science Works’. Such difficulties might perhaps have been anticipated for at least three reasons. First, unlike the other components of the science national curriculum, this aspect of science education was not so much an attempt to consolidate existing practice as to impose curriculum change. Secondly, the demands of assessment and reporting inevitably reduced any account of how science works to a practice that could be assessed. The consequence has been an emphasis upon the processing of data, the handling of variables and a set of low level practical skills. Thirdly, and perhaps the most important difficulty of all, and one that remains, is that science is an activity that requires not simply technical skill but also creativity and imagination. The encouragement and development of these qualities of originality does not comfortably alongside the demands of statutory assessment.

Capturing the essence of a creative and imaginative activity is never easy. Scientific discovery is a private matter and, as Sir Peter Medawar observed, the delight associated with it, or the despair of finding it illusory, does not travel well. This is an obstacle that confronts not only schools but also all forms of informal science education, whether in hands-on science centres, the print and broadcast media or biographical accounts by scientists themselves.

It is perhaps somewhat more straightforward to avoid presenting a distorted view of how scientific knowledge is sought and validated and there is undoubtedly some room for improvement here. School science has for too long been obsessed with teaching what used to be called ‘scientific method’, of which the ‘How science works’ in the present national curriculum is simply the latest manifestation. If I may refer again to Medawar, it was he who challenged us many years ago with the assertion that scientists pay no serious attention to the question ‘What is scientific method?’, adding that those that do are none the better scientists for doing so (Medawar 1982: 84).

The media, too, have a role to play here, although the difficulties they face should not be underestimated. The role of the media is to present news and the commitment of the journalist is to a story, a story that has to be sufficiently newsworthy to be published in competition with other news items demanding attention that day or that week. Presenting that story often requires reducing complex and specialist scientific concepts and language into something more readily accessible and, if I may use the expression, ‘giving it an angle’. Metaphors and analogies abound. Some are negative or pejorative: Pandora’s box, moral nightmare, thin end of the wedge and Frankenstein’s monster come immediately to mind. Others, perhaps rather fewer, are more positive. Examples include magic bullet, Holy Grail, stem cell miracle. All such expressions are overworked and, I contend hinder, rather than help, the public understanding of science and thus any informed engagement with it.
There is, however, a more fundamental and difficult issue to do with science and the media. If the media are to present something of the uncertainty and excitement of science in the making, it will be necessary to report scientific findings that are not yet, and may never become, part of the established scientific canon. It is by no means clear how this can be achieved and some of the risks of such reporting are clear, as the MMR example and an earlier controversy over Vitamin K and childhood cancer, among many others, clearly show.

I have tried to show that a diverse public engages with the sciences in different ways and at different levels. Some, a minority I suspect, will simply be excited by what science has to say and want to understand more about topics like the origin of the universe or how human stem cells can develop into organs as different as the brain and kidneys. Some will be interested and engaged when science, often through technological development, impinges on their everyday lives and concerns, such as nuclear power, the inheritance of chromosomes linked strongly to disease or the siting of telephone masts. Other forms of engagement are less appealing, as when science is misdirected as pseudoscience or corrupted to serve an overriding political or religious ideology.

I want to suggest that if we wish to advance the public engagement with science, we need to acknowledge these different forms of engagement and accept that it is not sufficient to promote science itself, essential though that is. To return to a point I made earlier, we need to know much more about why individuals and societies behave as they do. There is now a growing research literature that is beginning to offer some significant insights here, although that literature is very diverse, encompassing such fields as management, cognitive and social psychology, neuroscience and behavioural economics. Work in psychology tells us that judgements in the face of uncertainty are frequently based on a limited number of simplifying heuristics rather than on more extensive algorithmic procedures (Gilovich, Griffin and Kahneman 2002). In behavioural economics, human irrationality is now increasingly taken as a given, rather than, as in classical economic theory, some kind of epiphenomenon (Thaler and Sunstein 2008). There is, I believe, much of relevance to the engagement of science with the public that can be learnt from these and related fields that explore the basis on which people make decisions. To return briefly to the MMR example, the scientific/technical assessment of risk does not reflect the way most people think about risk. What matters more to people are factors such as a lack of control over what might happen, the potential for irreversible effects and a threat to the future of their child’s well-being, along with their personal and vicarious experience that they judge relevant. These factors are not addressed satisfactorily simply by quoting data from the World Health Organization.

In sum, therefore, while much has been achieved in engaging the public with science, my guess is that we are unlikely to make significant further progress without knowing more about the decision making process and without a better understanding of our present predicament, with its lack of trust in scientific expertise, the enduring appeal of the pseudo-sciences, and the raiding of science to support backward-looking political or
religious beliefs. If as the Secretary of State for Science and Industry put it in a consultation document issued in July of this year: ‘We must all learn to make better, more informed decisions’, we must, in my view, know more than is currently the case about how those decisions come to be made.

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