REVIEW

Understanding the receivers and the reception of science’s uncertain messages

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Although much work has been done by scientists in developing communications to non-scientist audiences, much less attention has been given by them to the ways in which those messages are interpreted. Here, I look at the published work that examines the issue. I focus on three contexts in particular: debates over the triple vaccine for measles, mumps and rubella, the impacts of the Soufrière Hills volcano on the inhabitants of the island of Montserrat and the public communication of the results of climate change research. Several common themes emerge. The most important conclusions are that scientists communicating with the public need to develop their methods deliberatively, involving their target audiences; and that they need to avoid undue dependence on traditional media and public authorities for such communication, and to develop multiple channels to those audiences, including Internet-based and more traditional social networks. Their approach to communicating uncertainty should depend on the context but, except in some extreme emergencies, transparency is generally a virtue. Above all, they need to persist in such public engagements even when the going is rough and extends over long periods. They need support in doing so.

Keywords: uncertainty; communication; public

1. Introduction

From time to time, in the perception of researchers in the natural sciences, the world loses its senses, and their core values of evidence-based understanding are seemingly at risk. Such perceptions—arising, for example, in the UK in public debates over genetically modified crops, the measles, mumps and rubella (MMR) vaccine and climate change—may be exacerbated by a feeling that some highly visible parts of the media are actively hostile to science.

In such circumstances, even those researchers talented in public communication have on occasion concluded that their efforts are a waste of time—signals lost in a noise of irrationality—and have retreated into silence.

Luckily, such episodes of distrust about science are relatively infrequent and tend to be confined to the debate in question rather than to science as a whole, and pass in time. Meanwhile, survey after survey of publics show that, at least in

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quieter times, scientists tend to be among the most trusted sources of information. Yet, even then, when time can be taken to craft messages appropriately, the possibilities of miscommunication are underestimated by the communicators. Given the importance of these messages, such miscommunication needs to be anticipated and addressed.

The values of openness and transparency in communication to stakeholders and publics, not to mention a modicum of due humility, necessitate an explicit acknowledgement of scientific uncertainties. But this obligation flies in the face of a strong concern that expressed uncertainties can themselves undermine public trust. Resolution of this contradiction depends on the context and on how you tell it.

I shall discuss the challenges arising in three examples in which science has fed into issues of public concern: the triple vaccine for MMR, the continuing eruption of the Soufrière Hills volcano on the Caribbean island of Montserrat, and climate change.

I shall use these contexts to exemplify the principal focus of this paper: how science’s messages, uncertainties and all, are received by broader audiences, and the lessons that can be learned for improved science communication.

It is all too easy for policy-makers and science-based institutions to communicate to stakeholders and publics and miss their targets because of an inadequate awareness of how those audiences are comprehending, interpreting or rejecting those communications, and the factors influencing such encounters. I have taken the invitation to give this paper as an opportunity to explore some of the published studies of these issues, in particular those by social scientists.

I have also talked to several journalists in the national media about their experiences in dealing with scientific uncertainty, while also thinking of my own experiences. Issues of undermined trust, of conflicting citizens’ values, of inadequate available knowledge and of dissent between scientists repeatedly pose challenges for science journalists, and this has influenced my choices of examples.

This paper is not only about communicating to the media. I also want to emphasize the need for communicators to think proactively about diverse channels of communication in responding to these challenges.

2. Measles, mumps and rubella: the science

The MMR vaccine—a shot of live-attenuated viruses of MMR—was licensed in the USA in 1972 and introduced in the UK in 1988. Following the initiation in 1998, by Andrew Wakefield and co-workers, of the debate over a possible link between the MMR vaccine and autism, a number of studies were carried out to assess the epidemiology and biology of such a link.

The US Institute of Medicine’s Board on Population Health and Public Health Practice concluded that the epidemiological evidence favoured rejection of the hypothesis that there is such a link. It concluded that the biology amounted only to a theoretical possibility, and that public health policy should not be changed on the basis of the hypothesis [1].

Similar conclusions were reached by at least nine other major reviews, including two by the Medical Research Council in 1998 and 2001, and one commissioned by the World Health Organization published in 2004. (For an overview in 2005

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of individual papers and meta-analyses, see a presentation by Elizabeth Miller, available from the Health Protection Agency at http://www.hpa.org.uk/Topics/InfectiousDiseases/InfectionsAZ/MMR/Presentations/).

3. Measles, mumps and rubella messages and their interpretation

Much has been written about the MMR debate in the UK, not least about the role of the media. For example, a media analysis and public survey conducted in 2002 led to the conclusion that the media provided a misleading sense of balance of scientific views, with a corresponding false public impression that the weight of evidence on either side was equal [2]. Some publications in particular—notably The Sun, the Daily Mail and Private Eye—adopted a more campaigning stance questioning the scientific consensus.

In 2002, the Science Media Centre (SMC) held an invitation-only meeting involving participants from the media, the Department of Health and other research and health agencies and charities, non-governmental organizations and social scientists. The meeting was an attempt to gather lessons that might be learned from the media debates. According to the report of the meeting (available at http://www.sciencemediacentre.org/uploadDir/487adminmmr_report.pdf), one of the consensus conclusions (despite many divergent views about the debate) was the importance of scientists and their institutions being able to respond to media reports not only in the immediate responsive sense but also in a more deliberate and strategic manner, particularly by stimulating longer feature articles. This was because media reports of research focused on new results, but tended not to provide an account of the cumulative state of science, yet always referred to the opposition to the scientific consensus. The treatment of maverick scientists was also highlighted—the views of Andrew Wakefield and co-workers were too seldom challenged by the media.

Two other conclusions also emerged: the scientists lacked a conveyed persona that was empathetic to parents’ concerns; and parents and the public in general may have been less concerned about measles than the disease merits, given their experience of it as a low-risk childhood illness. Both of these factors—scientists’ perceived persona and direct public experience of harm or the lack of it—will also arise in other contexts discussed later.

One segment of the report highlights the issues well, and is worth reproducing here:

Others argued that if we adopt the model of openness and transparency, a ‘risk versus benefit’ analysis could be presented to the public. Unfortunately, this is very difficult when the risks are unknown, or vanishingly small. It is also much harder to convince someone of the benefits for the whole population, rather than to the individual, because it involves recourse to epidemiology and statistics rather than personal experience. Within the constraints of a media soundbite, these subtle arguments can easily be lost. But that does not mean that scientists should stop trying, for as soon as they disengage from the media they automatically lose the battle. Like it or not, scientists may just have to trust the media not to adulterate their messages. Although the broadcast medium is often very constrained by a ‘soundbite’ culture, there would have been many opportunities for longer, more considered feature articles in the national press. In this forum, the subtleties of risk communication stand a much better chance of being negotiated successfully. According to several ‘media monitors’ present,
those articles were unfortunately few and far between. Similarly, the *Private Eye* special edition on MMR took a very tendentious approach that appeared on every news stand in the country, yet there was no equivalent publication putting forth the case in favour of MMR.

This highlights the need for sustained strategic efforts by scientists in public communication. Moreover, in my view, both the Economic and Social Research Council and SMC reports implicitly highlight a need for those giving out public messages to use all channels at their disposal: to be proactive in engaging with the traditional media, but also not to depend on those media only. Social media—currently including Twitter, Facebook, blogs and Wikipedia—should also be engaged, as should other networks in which people receive information and/or converse.

But whichever channels are used to deliver messages for public health based on science, there are deeper questions to ask about the messages themselves, even when the uncertainties as best understood by science are effectively negligible.

The MMR vaccine as a policy issue hinges on something intangible: herd immunity—the need to immunize as much as 95 per cent of the population in order to protect those who have not been vaccinated. It also hinges on values and beliefs that interact with parents’ views of vaccination. Where the media take sides in a controversy and where also there are parents resistant to vaccination for a variety of reasons, even comparatively ‘certain’ messages from science are easily overwhelmed in public discussion. There are complicating, countering factors even among parents who do not ultimately resist vaccination.

One approach used by social scientists to throw some insight on such factors is that of mental maps—used for decades in psychology and in marketing. A study by a team led by Baruch Fischhoff at Carnegie Mellon University is revealing by highlighting the limitations of supposedly reassuring messages from a government agency [3].

The researchers analysed various texts to highlight some of the key technical, operational and social concepts relating to MMR vaccination, and then constructed a narrative that incorporated and linked the concepts. They also interviewed scientists and parents of vaccinated children about the concepts that they associate with MMR, to draw out the expressed linkages between the concepts. The results are shown in figure 1.

The researchers then analysed communications by the US Centers for Disease Control and Prevention (CDC) and activists about the MMR vaccine. The CDC expressed the scientific consensus about the low degree of risk associated with the MMR vaccine. But, as the map in figure 2a shows, the language of the CDC message showed little understanding of the risk factors in the minds of the parents. The activist sites were more successful in this respect (figure 2b).

The conclusion that one can draw from this is straightforward. Although messages by government may not be sufficient to overcome the risk perceptions of some parents, it is surely necessary that they be crafted with the assistance of insight into the conceptual complexities among the target audiences, and by working with samples of the target audience as they are developed.

To recapitulate: discussions on the ways in which MMR messages were transmitted and received highlight the need for deliberative optimizing of messages for target audiences, and the need to develop channels to those audiences that are independent of the media.
The landscape of MMR has been one in which the divergences of views among researchers—however unbalanced—were and still are the driving factor in the debate, as was a lack of trust in ‘establishment’ science seized on by the media, while the population affected was and still is large. Issues of reflexive communication about vaccines are still critical; for example, in the context of influenza (e.g. [4]).

Next, I want to turn to a very different set of circumstances, in which the population was small, the divergence of scientific views was virtually zero and the role of the media was primarily supportive of the scientific consensus.

4. The Montserrat experience

There are hundreds of millions of people living within risk zones of the 1000-odd potentially active volcanoes worldwide. One such has been particularly closely studied by both natural and social scientists and provides a microcosm for some of the larger issues that I discuss here.
Figure 2. Models implicit in communications about the MMR vaccine from (a) an official source and (b) an activist Internet source. The thickness of each arrow corresponds to how frequently that link was mentioned [3].

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In 1995, bursts of steam and ash erupted from the Soufrière Hills volcano on the Caribbean island of Montserrat. This eruption followed several years of seismic activity. Over subsequent years, over half the then population of about 10,000 has been forced to leave the island and its capital Plymouth has been buried in mud. The disturbances continue—in February 2010, the vulcanian eruption generated pyroclastic flows and a lava-dome collapse generated clouds of ash affecting neighbouring islands.

Although the scientific understanding of the volcano is reasonably well developed, there are intrinsic uncertainties in such science that bear directly on aspects of the eruption that are of greatest public concern: the duration of the eruption and its impacts day by day. It is therefore worth summarizing some of those scientific uncertainties.

5. Montserrat science

The volcano has been studied before and during the period of the eruption. A physical model has magma continuously and steadily rising from the deep crust and entering a plumbing system involving a mid-level (12 km) reservoir and an upper level (6 km) reservoir, with a valve between the two reservoirs. This allows an observed cycle of three eruptions and pauses over the eruption period to be reproduced [5]. Another model can reproduce the observed cycles of dome collapse. It incorporates degassing of supersaturated magma, magma flow into the conduit, gas escape from the permeable magma, deformation of the conduit walls and the friction between the walls and the plug at the top of the conduit [6].

One might hope that such models could address the duration of the current episode of volcanicity. Unfortunately, even though one can estimate the proportion of stored magmas that have reached the surface at any one time, the exact content and behaviour in terms of fluid phases and their interactions with the surrounding rock cannot be resolved by the models, leaving major uncertainties.

A different approach to assess the duration of the period of activity is to examine the data from similar systems and look for patterns. Sparks & Aspinall [7] gathered data of 137 dome-forming eruptions from the Smithsonian Institution database and fitted them to a probability distribution model. Though there are several qualifications in such data fitting, the authors conclude that there is a 50 per cent probability that the current eruption will last beyond 20 years, and a 5 per cent probability that it will last for more than 180 years.

Another need for scientific analysis arises in the quantitative assessment of risks from pyroclastic flows, in which gas and rock move down a mountain slope at speeds of several hundreds of miles per hour. Historical data show that 90 per cent of people directly affected by flows are killed. Policy-makers need to understand the threat to different parts of the island in the long term, and the exact threats from particular eruptions in the short term. Sparks & Aspinall [7] discuss an assessment of such threats over a six-month window in a particular area of the terrain. Flows are caused by dome collapses following a period of dome extrusion, though the collapse can also be triggered by rainfall. Based on
empirical correlations and models of lava dome collapses and the possible ensuing pyroclastic flows, the panel concluded that collapses above a threshold volume (3 million m$^3$) would have a high probability of reaching the area in question.

A key gap in predictability from physical models is in the exact direction of dome growth and also exactly how such growth will lead to flows in particular directions. Accordingly, the risk assessment process had to call on expert judgement, using a technique known as ‘expert elicitation’. The latter, which I will discuss in more detail later, involves a formal process by which the judgement of several experts is gathered, weighted and aggregated. The group considered models and all the available data of previous collapses and flows, and assisted in estimating the likelihood of impacts in particular regions of the island over the periods in consideration, and accordingly to estimates of probabilities of casualties exceeding particular numbers over the period. Thus, officials were provided with quantitative risks for different regions of the island, allowing different policies to be evaluated in those terms. Figure 3 shows the reductions of risk to inhabitants of a particular region of the island—the Belham Valley area—as a result of two different approaches to evacuation.

6. Publics and Montserrat

There have been substantial studies by social scientists of the circumstances of Montserrat, in which issues of trust in information, the roles of scientists, the political and social context of advice and attitudes to risk have all been explored. The results discussed here were reported by Haynes et al. [8,9].

At the time of the research (2002–2003), volcanism was intense and evacuations were taking place. For both studies, 35 members of the public and 31 scientists and authorities were interviewed, including UK government officials, Montserrat government officials, crisis leaders, religious leaders and representatives of the media. What follows is a summary of some key conclusions.

(a) Trust

A key issue—indeed a determining issue for success or failure—in communication is trust. Of all sources on the island, family and friends were given highest trust as sources of information by the public, with scientists coming a close second—much higher than the authorities. The local media were also highly respected, in sharp contrast to the global media, who were the least trusted of sources.

The high trust of scientists was associated with perceptions of their competence, their reliability, their openness and perceptions that they cared. Those scientists who were seen as human beings gained a particular advantage! Receiving information directly from scientists greatly aided its credibility, rather than the same advice being channelled through intermediaries. Notably, trust in scientists increased according to their perceived independence—for example, who employed them.

(b) Networks and their usefulness

The strong trust given to friends and relations allowed misleading assertions to gain credibility rapidly. Moreover, where scientists’ descriptions or forecasts

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conflicted with local experience, trust was notably undermined and conflicting messages were spread.

On the other hand, the high trust given to friends and families, as well as to religious leaders, allowed opportunities for appropriate messages to be disseminated if such networks were well used. The latter was only possible as a result of direct engagement over extended periods. (The role of religion in communication of volcanic hazards worldwide may be non-negligible—a local

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order of nuns was used to convey information to Aeta Indians on the slopes of Pinatubo, and religious leaders are influential on Montserrat. These and other examples of communication networks are discussed in a broad overview of volcano risk communication and risk reduction by Barclay et al. [10].

While one cannot as readily use family and social networks where issues confront large and diverse populations, there is a message here, as in the case of MMR, about the importance of proactively developing many lines of communication for key messages among, for example, networks of citizens whose interests do not directly conflict with getting the scientific message across.

(c) Scientists’ involvement

The research also highlighted another message that featured in the SMC’s report on MMR—the importance of involving scientists directly in public communication. On Montserrat, the involvement of scientists in direct communication with the public was quite intensive in the early years but tailed off. Scientists felt that they had done their bit in educating the population, and indeed that their involvement led to their role being misunderstood.

The evidence suggests that scientists on Montserrat and in crises more generally, beyond their traditional role of providing technical advice to the authorities, will rightly be under pressure to engage with the public. Appropriate ways of undertaking such engagement are endorsed as good practice, not only by these surveys but also by the International Association of Volcanology and Chemistry of the Earth’s Interior [11] in its code of good practice for volcanologists in such circumstances.

There is thus a need to prepare and support scientists for such additional responsibilities.

(d) Experience of events

The experience of impacts from previous events played a role in recipients’ interpretation of messages about uncertainty and risk. The role of experiencing a volcanic event on people’s perceptions of the risks was double-edged: on the one hand, it greatly amplified people’s awareness of just what the risks entailed, and thus the influence of those risks on behaviour. But it also tended to amplify the sense of safety among those who had come through unscathed as well as some of the authorities.

The influence of experience, and the lack of it, in responding to public science-based advice also surfaced as a consideration in the case of MMR, and will be discussed further in the context of climate change.

(e) Perceived reliability of science

An important issue for all involved in a science-related debate in which forecasts of the future can be important surrounds the perception of reliability as influenced by ensuing events. On Montserrat, uncertainty remained problematic in public and authorities’ perceptions of scientists. No matter how much effort was put into conveying the uncertainties, whether in descriptions of the science or in forecasts of future eruptions and their impacts, an alert that turned out to be unfulfilled was judged as ‘false’ and hence a failure.
Moreover, the evident inability of scientists to reduce the uncertainties was also seen as a failure. This may have been partly because the authorities interpreted the uncertainties with too much precision, homing in on one extreme end for their own reasons.

I interpret this last paragraph as highlighting the need for the scientists and their institutions to avoid not only undue reliance on the media but also undue reliance on public authorities for conveying the messages of science.

Finally, a point about diversity of scientific opinion. During the period of investigation, there were no episodes documented in which volcanologists clashed openly in the advice given. The social sciences literature, as well as the code of conduct for scientists in volcanic crises, stresses the need to speak with one voice in such situations.

Of all these observations from the social science studies, this consideration of public unanimity seems to be the least generalizable to larger debates, given that, in most national or global challenges, scientists will have diverse views. The justification of public unanimity is to maintain essential trust in a period of emergency. Such considerations do not apply to long-running debates. Moreover, as I shall discuss later, there are ways of confronting diversity of scientific opinions directly, and thereby even making an asset of it.

The discussion so far has, I hope, highlighted some key issues of communicating uncertainty in the context of two societally charged arenas of public policy and public perceptions of science. I shall next turn to my final example of such an arena: climate change research and its communication. Here, we shall see not only manifestations of similar factors but also an example of uniquely deliberative efforts in communication of the scientific uncertainties—though some (including me) would say that, while extraordinarily deep, the deliberations are still too restricted in breadth.

7. Uncertainties in climate science

In the Montserrat case, trust in scientists was high, even though there were some uncertainties in the science. This is consistent with polls over the years that suggest that scientists rank high in public trust.

In the case of MMR, the science was exceedingly robust, but trust in scientists was undermined in those parents whose perceptions of risk were intrinsically strong, who were influenced by media campaigns and who were ready to adopt a theory that the scientific establishment was trying to suppress innovative research.

In the case of climate change, a large range of complex factors and uncertainties play into the public’s response to the messages from science.

In his book *Why we disagree about climate change* [12], Mike Hulme points to a number of factors underlying public debates. According to his overview, we disagree about climate change because:

— science is not doing the job we expect or want it to do;
— we ascribe values to activities, assets, constructs and resources differently;
— we believe different things about our duty to others, to Nature and (for the religious) to our deities;

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— we understand global development differently;
— we evaluate risks differently; and
— we receive multiple and conflicting messages about climate change and we interpret them in different ways.

The Royal Society Discussion Meeting on ‘Handling uncertainty in science’, and the writing of this paper, occurred at a time when trust in climate scientists had undergone a steep decline. At the time of writing, the roles of activists and of the media, and the roles and actions of the institutions at the heart of this phenomenon—the University of East Anglia and the Intergovernmental Panel on Climate Change (IPCC)—have yet to be fully analysed. The following discussion does not address such major disruptions, and on comparison may appear to be fiddling while Rome burns. It is my belief, however, that this particular conflagration, while intense and not under control, will prove to be of limited impact in the longer term. I maintain that the regular operational aspects of communication need just as much attention, because that can lead to a more robust and a mature culture of proactive communication and considered reception of information and advice.

I want to focus on the last two of Hulme’s aspects of disagreement by examining key issues in the communication of uncertainty. However, I should first mention the broader picture of the psychology of responses to climate change, as discussed in a comprehensive overview of psychology and global climate change commissioned and published by the American Psychological Association (APA; [13], available at http://www.apa.org/science/about/publications/climate-change.aspx).

Among its discussion of many facets of the topic, the review points to a wealth of literatures about several aspects of psychology that lead many citizens, in various contexts, to downplay the long-term threats from climate change, in strong contrast to the perceptions of climate researchers, whose closeness to the concepts and whose facility with analysis and statistics will make the threat appear much more immediate. The reasons for downplaying range from the lack of direct relevant experience, inimical political or other values, to feelings of powerlessness in the face of threatening messages.

The importance of experience—relevant to all three examples discussed here—can be expressed by psychologists as a distinction between an associative or affective response—directly affecting the emotional centres of the brain—and an analytical response that is less direct therefore requires more work by the brain. This difference can lead to correspondingly different responses to the same information.

Another key message from psychology, according to the APA review, is the extent to which perceptions of risk and uncertainty are influenced by social networks. Such networks can play a key role in representation—shared assumptions and understandings about the social and physical world. Social processes can also amplify or attenuate perceptions of risk in the interaction between risk signals—images, signs and symbols—and psychological, social, institutional and cultural processes [14]. This is reminiscent of points mentioned previously, in terms both of the positive and negative influences of such networks and of their importance as avenues for the communication of information and advice.
Table 1. Mapping of probability words into quantitative subjective probability judgements, used by working groups 1 and 2 of the Intergovernmental Panel on Climate Change Third Assessment based on recommendations developed by Moss & Schneider [15].

<table>
<thead>
<tr>
<th>word</th>
<th>probability range</th>
</tr>
</thead>
<tbody>
<tr>
<td>virtually certain</td>
<td>&gt;0.99</td>
</tr>
<tr>
<td>very likely</td>
<td>0.90–0.99</td>
</tr>
<tr>
<td>likely</td>
<td>0.66–0.90</td>
</tr>
<tr>
<td>medium likelihood</td>
<td>0.33–0.66</td>
</tr>
<tr>
<td>unlikely</td>
<td>0.10–0.33</td>
</tr>
<tr>
<td>very unlikely</td>
<td>0.01–0.10</td>
</tr>
<tr>
<td>exceptionally unlikely</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Table 2. Mapping of probability words into quantitative subjective judgements of confidence as used in the Intergovernmental Panel on Climate Change Fourth Assessment.

<table>
<thead>
<tr>
<th>word</th>
<th>probability range</th>
</tr>
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<tbody>
<tr>
<td>very high confidence</td>
<td>at least 9 out of 10 chance</td>
</tr>
<tr>
<td>high confidence</td>
<td>about 8 out of 10 chance</td>
</tr>
<tr>
<td>medium confidence</td>
<td>about 5 out of 10 chance</td>
</tr>
<tr>
<td>low confidence</td>
<td>about 2 out of 10 chance</td>
</tr>
<tr>
<td>very low confidence</td>
<td>less than 1 out of 10 chance</td>
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8. The language of uncertainty

I now want to illustrate the degree of discussion that goes on within the climate research community about the language of uncertainty, and also some evidence as to how, even so, it is misinterpreted.

The IPCC serves as a focus for such discussions. The panel is structured into three working groups, on the science (WG1), on impacts and adaptation and vulnerabilities (WG2) and on mitigation (WG3). In each of the major assessments, cross-cutting guidance is generated on generic issues, including communicating uncertainty. An important example of such was in the discussions of communication of uncertainty: a paper by Moss & Schneider [15]. This document advocated the development of consistent language according to numerical levels of confidence. As a result, the 2001 Third Assessment Reports of WG1 and WG2 adopted language associated with quantitative subjective probability judgements (table 1).

The IPCC’s Fourth Assessment Report in 2007 drew a distinction between confidence and likelihood, noting ‘The uncertainty guidance provided for the Fourth Assessment Report draws, for the first time, a careful distinction between levels of confidence in scientific understanding and the likelihoods of specific results. This allows authors to express high confidence that an event is extremely unlikely … as well as high confidence that an event is about as likely as not’. The mapping of probability phrases onto quantitative subjective judgements of confidence used in the IPCC’s Fourth Assessment Report is shown in table 2.
Note the subjective nature of the judgements being characterized. Such judgements, based on data and expert evaluation, represent a Bayesian assessment whose outcomes may change as the data and experts themselves move on. Also within climate science, and in contrast, one may derive a forecast based on a probability distribution derived from defined combinations of data and models and their parameters—a frequentist approach whose outcome is fixed, albeit dependent on the assumptions underlying the forecast.

In discussions ahead of the IPCC’s Fifth Assessment Report, scheduled to be completed by September 2014, discussions about language will no doubt include attention to such distinctions. For example, the climatologist Myles Allen (2010, personal communication) urges a distinction in language that should be used between frequentist confidence intervals and Bayesian posteriors. He provides three examples of the use of ‘likely’ that present quite different types of judgement:

Contrast:

— ‘It is likely that there has been a significant anthropogenic warming over the past 50 years...’ (reporting hypothesis tests);
— ‘The 2010s are likely to be warmer than the 2000s’ (reporting calibrated results of decadal forecasts); and
— ‘The best estimate for the low scenario (B1) is 1.8°C (likely range is 1.1–2.9°C)’ (subjective judgement).

He recommends:

— When a hypothesis test can be performed or a simple frequentist interpretation is possible, use ‘it is likely that...’, i.e. use the passive tense, as such likelihoods don’t belong to anyone.
— When reporting expert judgements on the outcomes of Bayesian studies, use the first person plural ‘we are confident that’—a judgement needs a judge. For example, in the Fourth Assessment Report, it is not possible to say ‘It is very unlikely that SLR will be >2 m over this century’ (there are no data available to reject this null hypothesis). But in the Fourth Assessment Report it is possible (perhaps) to say ‘We are very confident that SLR will be <2 m over this century’ (statement of authors’ judgement in the light of data, models and understanding).

Such considerations of language are important not only for the grand assessments periodically produced by the IPCC but also for its reports on specific topics including the increasingly important subject of attribution of climate change. Attribution science (the context in which Allen’s remarks arose) seems likely to become as charged as any other aspect of climate research for two potential reasons: where damage can be attributed to man-made climate change, countries may become eligible for international funds for adaptation; and where damage can be even partially attributed to the acts of a particular nation or company, legal liabilities may ensue [16,17]. Clearly, the communication of uncertainty will be a central feature of such debates.
9. Communicating climate uncertainties

A document that provides a particularly thoughtful overview of uncertainty, and much useful guidance as to the practice of communicating it, is ‘Best practice approaches for characterizing, communicating and incorporating scientific uncertainty in climate decision making’, written by a team led by Granger Morgan at Carnegie Mellon University ([18], available at http://www.climatescience.gov/Library/sap/sap5-2/default.php). It discusses the many ways in which uncertainty can be elucidated and conveyed, including the roles of judgement and expert elicitations. It provides an overview of many of the issues about language that have been discussed here. It also provides a useful overview of the topic that I wish to turn to next: the comprehension and misunderstandings of messages by their recipients—i.e. the cognition of communication.

As Morgan et al. [18] summarize, there have been many studies of the variation in interpretation of phrases of likelihood. A striking example is that of the advisory committees of the Executive Committee of the US Environmental Protection Agency, Science Advisory Board (SAM). On being asked to ascribe a numerical value to the word ‘likely’ in relation to the probability that an agent was a human carcinogen, one SAM member placed it in a range of about 0.9 or greater, and another, at the opposite extreme, ascribed it to a range of 0.001 or greater. The other members came up with values in between. There was a corresponding variety of interpretations of ‘not likely’ [19].

More recently, researchers at the University of Illinois at Urbana-Champaign specifically explored the interpretation of IPCC language described already [20]. Over 200 students and faculty were shown 13 probabilistic pronouncements from the IPCC’s Fourth Assessment Report. One group was given none of the quantitative guidance of equivalent quantitative subjective probabilities supplied in the analysis report by the IPCC. Another group was provided with the numerical tables of probabilities. Each group was asked to give an estimate of probability represented by the sentence, and the highest and lowest values consistent with the language.

The results show significant mismatches between writers’ intentions and readers’ comprehensions. As the authors put it: ‘Consider the [IPCC Fourth Assessment] statement that “average Northern Hemisphere temperatures during the second half of the 20th century were very likely higher than during any other 50-year period in the last 500 years”. It is hard to believe that the authors had in mind probabilities lower than 70 per cent, yet this is how 25 per cent of our subjects interpreted the term very likely!’

The results were independent of the attitudes of respondents to climate change. The results did demonstrate a positive impact of including simultaneously both verbal and numerical characterizations of subjective probability.

A question raised more generally is whether tables of particular numerical equivalences with language can be applied generically, i.e. to contexts other than climate change or to different aspects of climate change. The authors argue that to apply such a uniform approach is misguided, given that the state of knowledge and the ranges of the uncertainty will differ. What is more important, they say, is to use consistent language within the context, provide the numerical range at the same time and adjust the ranges to reflect the assessed uncertainty.
The paradoxical and unintended consequence of the “one-size-fits-all” solution adopted by the IPCC are that the report may convey levels of imprecision that are too high, and that many probabilities may be interpreted less extremely than intended by the authors . . . , which may lead to underestimation of the magnitude of the problems being discussed.

In this section, I have highlighted ways in which verbal communication has received much attention in one prominent area of public discussion, while also showing that the cognitive aspects of the interpretation of such language is more problematic than has perhaps been appreciated by those crafting climate messages.

This does not negate the importance of using language with consistency and care, given political and other sensitivities. In particular, the benefit of consistently deploying both language and numerical values is clearly demonstrated.

Nevertheless, it does suggest that more should be done to take cognitive aspects of interpretation into account in crafting the messages. This could be done, for example, by relating such language and numerical values to more familiar examples, so that readers’ comprehensions are better anchored and more sensitized against misinterpretation.

It also suggests that the IPCC itself should engage more with its target audiences in crafting its language.

10. Visualizing uncertainties

Language is one mode of communication of uncertainty. Another is visualization. Morgan et al. [18] provide a set of visual renderings of the language discussed already. They also display a ‘box plot’ visualization of a probabilistic estimation, including range, percentiles, the median and the mean (figure 4).

One problem facing communicators and the media is where there are diverse and even divergent judgements within the research community about a particular scientific judgement. It is common to hear academics complain of a false sense of balance given by quoting a majority view and an opposing view held by a tiny
minority in language that ascribes them with equal weight, as was documented in
the case of MMR and certainly occurs in coverage of climate change. Visualization
provides a way of illustrating the range of views in a much more transparent
way (I shall return to the media’s attitude to uncertainty and visualization
later). But, before discussing this, I need to illustrate a technique that perhaps
best reveals the range of judgements within a community of researchers: expert
elicitation.

11. Expert elicitation

In the discussions of Montserrat and climate change, I referred briefly to the
technique of expert elicitation. This method has been developed as a way of
bringing a range of expert judgements to bear on quantitative questions in order
to complement, or make up for the unavoidable absence of, analytical treatments.
To my mind, its value is that it brings to the fore, and makes explicit, the role
of expert judgement within a broader modelling context. I will illustrate the
technique with an example in climate change research that highlights its potential
contribution not only in science and policy-making but also in communication of
uncertainties. I shall also highlight the uncertain status of expert elicitation in
the eyes of researchers and journals.

The technique in essence involves a number of experts who are asked a specific
question that requires a probabilistic estimate as a response. Examples that I
am aware of include that associated with the Montserrat volcano, the dangers
of an infectious disease, risks inherent in a potential radioactive waste repository
and the risk of dam failure [21]. Here, I shall discuss several examples in climate
change science.

Expert elicitation makes explicit the distinct judgements and estimated
uncertainties of experts rather than their pooled ‘optimized’ judgement (of the
sort arrived at, for example, by a Delphi process). The experts submit themselves
to calibration tests at the outset, responding to questions of general knowledge
and judgement as well as those relating to their discipline. These tests allow
the person running the exercise to assess their degree of confidence, and their
tendencies to overstate or understate (see Aspinall [21] for further discussion and
references).

The experts are then asked to spend a period of time (typically a day)
discussing with each other the specific question at issue. At the end of the exercise,
they are typically each asked to give their best estimate of the upper and lower
bounds of a quantity, the median value and the upper and lower quartiles. These
can then be presented as box diagrams.

An example of the potential added value of expert elicitation for policy-
making can be found in climate change research. A key uncertainty in
climate change modelling lies in the contribution of atmospheric aerosols
to the balance of radiation entering and leaving the lower atmosphere—the
troposphere—at its boundary with the stratosphere. The uncertainties require
the application of researchers’ judgements in assessing such contributions. An
expert elicitation to estimate the radiative forcing of aerosols revealed a variety
of assessments of the probable ranges and likely values of the radiative forcing of
aerosols [22].

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One issue arising from this study relates to the IPCC assessment of the same quantity. As discussed by Morgan et al. [18], if one compares these explicit ranges of expert judgements with the presentation of the IPCC’s Fourth Assessment, the lower and upper 5 per cent values of significant numbers of the experts lie outside the 90% confidence intervals of the IPCC, suggesting that the IPCC estimates ‘are tighter than those of many individual experts who were working in the field at about the same time as the AR4 summary was produced’.

Another more general issue relates to the status given to expert elicitation. The aerosol elicitation was commissioned for the IPCC’s Fourth Assessment, but there was no consensus achieved as to the status of such an elicitation as scientific evidence; so it was not included in the chapter of the WG1 report on aerosol forcing.

I must come clean at this point and acknowledge that journals also have reached this conclusion in the past, and apparently have rejected such exercises for that reason alone. Nowadays, we at Nature would, in principle, have a more receptive attitude.

12. Visualizing uncertainties (continued)

The question of the uncertainty in forcing by aerosols is a technical one, not necessarily of great public interest. But the same is not true of a more fundamental characteristic of the Earth’s atmosphere: the climate sensitivity. This is the equilibrium warming that would arise from a doubling of the global mean carbon dioxide content of the atmosphere. This bears directly on the contentious issue of man’s impact on climate. The results of an expert elicitation about this quantity [23] are shown in figure 5. Here is an illustration of a community consensus about climate sensitivity—almost. All but one of the experts agrees that the impact of carbon dioxide will be significant.

It is notable that this agreement arises despite these experts’ judgements differing significantly on other aspects of global temperatures. In particular, their judgements of a related quantity, the pole-to-equator temperature gradient, were found to differ substantially.

I want to highlight figure 5 for its relevance to public debates about climate change. This diagram seems to me to be of potential value for any journalist wishing to understand a community view, and might even possibly be of value, if simplified, as an illustration of such factors. And there are some debates where expert judgements can show where an outlier researcher maverick is situated in relation to his or her peers—something that may be of crucial value in helping policy-makers and publics form a view about a hotly debated issue.

In that context, figure 5 not only illustrates a broad consensus but also includes a notable detail: expert 5, who is extreme in two senses—he not only gives a minimal value for the impact of carbon dioxide on the atmosphere, but also displays minimal uncertainty in his estimate. Experts usually undertake elicitation exercises under conditions of anonymity, so all I will say is that this scientist is eminent, and has often been quoted in media stories as providing a more sceptical view of climate change.

Science is not a democracy, and the power of scepticism is justly one of its most celebrated virtues. Thus, this diagram is not a critique of any of the experts represented—it is, rather, about as objective as one could get in portraying...
Figure 5. Surface temperature change. Box plots of elicited probability distributions of climate sensitivity, the change in globally averaged surface temperature for a $2 \times [\text{CO}_2]$ forcing. Horizontal lines denote the range from minimum to maximum assessed possible values. Vertical tick marks indicate the locations of the lower 5 and upper 95 percentiles. Box indicates the interval spanned by a 50% confidence interval. Solid dot is the mean, and open dot is the median. The two columns of numbers on the right-hand side of the figure report values of mean and standard deviation of the distributions [23].

the state of mind of a discipline’s experts. I maintain that it helps policymakers and publics to know who these experts are, and to be able to see how someone giving their views to journalists relates to his or her peers in his or her outlook.

13. Common issues and inferences

Here, I draw some general conclusions from my discussion of climate change, MMR vaccines and Montserrat volcanism.

Each unhappy episode of public debate about science is unhappy in its own way. But a clear message learned from any public debate is that there is an acute need for any protagonist, not least scientists and their institutions, to be prepared to respond very promptly to events as they arise, on a time scale of less than a day.
Such responses, while being conveyed to the media and the relevant decision-makers, should not depend on them alone. There is a need for a more strategic approach to communications, both in providing discussions of context and scientific background and in developing one’s own website and also the networks that will allow messages to reach their targets in multiple and reinforcing ways.

Another clear conclusion is that consideration of the audience is as important as consideration of the message itself. Such consideration needs to include representatives of the audience in developing the messages. This will not only optimize the conveying of uncertainty in a comprehensible way, but will also alert the communicators to the values and sensitivities in the intended audiences that might otherwise be missed. This process can be truly deliberative, in that the communicators may learn more from the insights gained than merely how to communicate better. Some would argue that much more of such deliberation is required in the case of climate change, where the IPCC’s discussions have tended to be confined to experts.

In all three examples discussed earlier, the role of citizens’ previous experience of impacts and the need to imagine possible futures in the interests of that direct sensitization was a factor to be considered in communication. This poses an interesting challenge for those seeking to communicate about risks and associated uncertainties: how to make the risk seem vivid and related to experience, without—at the same time—drawing overly simplistic analogies and also exaggerating the immediacy or degree of the risk. Such exaggeration—whether real or perceived—is a sure recipe for diminished trust in scientists. However, I would suggest that the development and communication of scenarios based on probabilistic modelling and documented scientific judgements can be both responsible and appropriately compelling in helping people fully consider risks.

A related issue is the balance of interests in discussing uncertainties at all: on the one hand, openness and transparency about the science can serve to increase trust; on the other hand, expressed uncertainties themselves can undermine it. It is my belief that the former consideration serves the public interest in the long run and should prevail, while the latter concern should inform the way in which messages are conveyed.

Attention to uncertainty is itself a challenge for the media in particular. News editors may find it intrinsically uninteresting or a complicating factor that merely serves to undermine the strength of a story. Nevertheless, there is a merit in publishing long features in which, for example, complex visualizations might appear. And a convenient illustration of, say, the diversity of scientific judgements, especially where it is unbalanced and relates to political debates, may gain traction and be widely reproduced.

Although the distinctions between data-based and scientifically judgemental forecasts or assessments lie beneath the radar of much scientific communication, there is a virtue in making them as explicit as possible—providing a paper-trail for those publics and stakeholders who wish to dig into the arguments, and indeed for researchers wishing to contribute to the organized scepticism that is their trade. In that sense, expert elicitations not only have the merit of helping address practical challenges but also can contribute to science.

My final conclusion relates to the active involvement of scientists in communication. Given that trust in scientists is generally high, their involvement
in communication is important—the Montserrat studies highlighted that particularly clearly, and there is no reason to think that this cannot be generalized to the broader debates also discussed here. As described already, the ways in which those messages are developed is crucial.

The pressures of such involvement—on researchers’ time, on their other accountabilities and on their nerves—can be acute. Support is crucial. But in such circumstances, long-term debates and perceived media and public hostility can wear away one’s willingness to cope. The earlier mentioned discussions suggest that withdrawal of researchers from the debate is dangerous to its quality and robustness. Their perseverance is essential.

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