

THE PSYCHOLOGY OF GLOBAL WARMING

Improving the Fit between the Science and the Message

BY BEN R. NEWELL AND ANDREW J. PITMAN

Insights from the psychology of judgment and decision making might help the climate community communicate global warming science to an often skeptical public.

Consider the following question: If a bat and a ball cost \$1.10 in total and the bat costs \$1 more than the ball, how much does the ball cost? If you are like many people, your immediate answer would be 10¢ (Kahneman and Frederick 2002). You would be wrong. Think a little and you will see why. This is a simple question and the answer is easy, but people still often get it wrong. Contrast the simplicity of this question with the complexity of global warming. Is there any hope of communicating such complex issues if many people fall foul on a simple mental arithmetic problem? Yes. These simple examples and the resulting errors can illuminate how we make decisions. Knowledge of these mechanisms can help

us understand how to communicate climate science to fit with the way humans process information. Our aim in this paper is to provide some suggestions for improving this fit.

Evidence for warming. The idea that Earth is warming partly because of the emissions of greenhouse gases to the atmosphere is one of the most certain concepts in natural science. The idea that greenhouse gases increase radiative forcing is an old idea that has withstood a variety of analyses to emerge intact (an accessible history is available on the Web site of the American Institute of Physics at www.aip.org/history/climate/co2.htm). The peer-reviewed papers that provide the evidence that human-induced emissions of greenhouse gases over the twentieth century have led to increases in temperature and changes in rainfall, wind, humidity, sea level, ocean acidity, snow cover, etc. have been assessed rigorously through the Intergovernmental Panel on Climate Change (IPCC) in a series of reports. No serious academic body, significant institution, or national government doubts the basic science (e.g., Somers 2009).

Despite this near total lack of evidence to the contrary, a significant portion of the public, journalists, and politicians emphasize their serious doubts about the science of global warming. This skepticism has increased as the level of scientific certainty in global warming has increased. For example, in a

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recent survey of U.S. residents, only 57% said that they believed global warming was happening, down from 71% in 2008 (Leiserowitz et al. 2010). Why has this “disconnect” (Mariconti 2009) between the science and the public/media perception of the problem occurred?

Many readers of the *Bulletin of the American Meteorological Society* (BAMS) routinely give talks based on the IPCC science. Clearly, the message that this science is robust and leads to a conclusion that we must act aggressively to reduce emissions is either not being heard, being dismissed, or not being acted on. This failure to get a clear message through is presumably one of the reasons for this disconnect. Thus, some effort to refine and hone the way in which climate scientists communicate their findings to the wider community appears warranted.

Interpreting evidence. How humans interpret evidence, how they react to evidence, and how they form views based on evidence are not related merely to the quality of the evidence. Psychologists, especially those with an interest in judgment and decision making, explore precisely these issues and can therefore provide insights into the impediments confronting the communicators of climate science. The role that psychology can and should play in the climate change debate was heralded almost 30 yr ago (Fischhoff 1981) and since then there has been an increasing amount of research at the intersection of psychology and climate science, especially in the last decade (e.g., Budescu et al. 2009; Fischhoff 2007; Fischhoff and Furby 1983; Hardisty and Weber 2009; Leiserowitz 2006; Moser and Dilling 2004; Nicholls 1999; Serman 2008; Stern 1992; Weber 2006). Our aim in this paper is not to provide a detailed synthesis of this literature: many relevant topics have been covered in much greater depth by other authors (e.g., Morgan et al. 2002); more modestly, we want to make BAMS readers aware of this literature, highlight what we find to be thought-provoking and relevant insights, and offer some brief suggestions for improving communication of the complexities of climate science. For more specific communication strategies, interested readers should consult some of the excellent resources listed in the “Further Reading” sidebar.

Insights from psychology. We have divided the paper into four sections, each of which focuses on a different “class” of psychological phenomena: sampling, framing, comprehension, and the process and perception of consensus building. The presentation of the psychological phenomena is preceded, in each

section, by a statement of a problem from the climate perspective along with reasons why the problem often leads to confusion on the part of the (lay) audience. The relevant psychological phenomena along with suggestions for how to “tackle” them are then presented primarily in the four main tables of the article. The accompanying text in each section provides further explanation of the phenomena listed in the tables and references to relevant articles in the psychology literature.

SAMPLING ISSUES: WHAT SAMPLES OF EVIDENCE DO PEOPLE USE WHEN MAKING JUDGMENTS?

By a “sample,” we mean the subset of information that a person uses to draw an inference or conclusion. We identify two key sample problems in global warming science: “weather versus climate” and “is it warming?” We will briefly summarize these problems before presenting some relevant psychological phenomena.

Climate phenomenon: Weather versus climate. No BAMS reader would confuse weather and climate, but the media and the general public routinely do. Who has not been confronted by “it was cold this spring, that global warming thing must be a myth?” You can replace “spring” with a single day, week, month, year, or decade. Or someone saying, “I remember it being much hotter when I was a child.” The IPCC addressed this issue in a frequently asked question in the Fourth Assessment Report (FAQ 1.2) and explained the nature of weather versus climate, the role of chaos, and the difference between a deterministic weather prediction and a statistical climate projection. However, the explanation is complex to the journalist, the policy maker, and the general public, despite every effort to use simple language. Understanding the explanation requires an appreciation of how the climate system works, through time, on a variety of spatial scales. Understanding time scales, the interactions of forcing and natural variability, evolution of various components of the climate on different time scales, and the projection of these onto changes in various systems is basic climate science. It is not, however, what the vast majority of people think about.

Climate phenomenon: Is it warming? Earth is warming and it is warming in large part because of the human emissions of greenhouse gases. The IPCC Fourth Assessment Report (specifically Working Group 1) provides a convincing defense of this statement. Of course, not every day is warmer than yesterday, not

every year is warmer than last year, and not every decade has to be warmer than the last decade. Some recent evidence points to the probability of some decades through the twenty-first-century cooling relative to the previous decade, whereas the overall trend through this century would be one of warming (Easterling and Wehner 2009). There will inevitably be some cold months, some deep snow falls, or some very cold days through the twenty-first century. Indeed, an intensification of the hydrological cycle or stronger storm tracks may increase the likelihood of some extreme cold events in the future. Global warming is, of course, about trends and averages at large spatial scales, and the averages are not commonly grossly affected by small changes in the frequency of rare events.

Psychological phenomena influencing samples of evidence. Table 1 identifies four psychological phenomena relevant to the sampling issues described earlier. With regard to the weather for climate problem, a relevant phenomenon is that of “attribute substitution,” whereby people tend to substitute difficult questions with ones that they find easier to answer (Kahneman and Frederick 2002). The bat-and-ball problem introduced earlier is a good example. The amount of \$1.10 is easily decomposed into \$1 and 10¢; 10¢ sounds about the right price for a ball, so we give that answer, even though a little more thinking tells us it is wrong.¹ Thus, when asked to think about changes in the climate (a complex spatial and temporal con-

¹ The correct answer is 5¢.

FURTHER READING

This is an annotated list of reading we recommend. We begin with something roughly equivalent to the frequently asked questions from the IPCC. We move from this through accessible “popular science” books written by academics all of which are consistent with the psychological literature. Finally, we recommend more specialized texts for the climate scientist who wants to develop a deeper understanding of the psychology of judgment and decision making

The Psychology of Climate Change Communication: A Guide for Scientists, Journalists, Educators and the Interested Public by The Center for Research on Environmental Decisions (downloadable for free online at <http://cred.columbia.edu/guide>).

This guide was prepared by a group of highly respected psychologists at the Center for Research on Environmental Decisions (based at Columbia University). It is a very readable overview of a wide variety of peer-reviewed work examining several facets of the psychology of climate change communication. An invaluable resource for climate scientists wishing to improve public presentations of their science.

Reckoning with Risk: Learning to Live with Uncertainty (U.S. title: *Calculated Risks*) by Gerd Gigerenzer. Published by Penguin. Gigerenzer is the Director of the Adaptive Behavior and Cognition Group at the Max Planck Institute for Human Development in Berlin. He has published widely on risk communication and this book brings together much of his work on how to understand and present statistical information.

Nudge: Improving Decisions about Health, Wealth and Happiness by Richard Thaler and Cass Sunstein. Published by Penguin. Thaler, an economist, and Sunstein, a lawyer, are both based at the University of Chicago. They have both published extensively on the intersection of psychology, economics, and law. This engaging book is an investigation into how an appropriate “choice architecture” can improve our decision making.

Risk and Reason by Cass Sunstein. Published by Cambridge University Press.

This is an examination of how reasoning about risk through a cost-benefit analysis can improve risk regulation. The book includes particular focus on environmental risks (e.g., global warming).

Risk communication: A Mental Models Approach by M. G. Morgan, B. Fischhoff, A. Bostrom, and C. J. Atman. Published by Cambridge University Press.

A highly detailed yet very accessible “field guide” to the use of the mental models approach to risk communication. It includes in depth discussion of global warming and climate change. The authors are experts in public policy, psychology, and engineering.

Straight Choices: The Psychology of Decision Making by Ben R. Newell, David A. Lagnado, and David R. Shanks. Published by Psychology Press.

An up-to-date and accessible text book-style introduction to many of the key findings in the psychology of judgment and decision making. The authors are all psychologists and have published in many areas of cognitive psychology including papers on learning, memory, causal and probabilistic reasoning, and decision making.

TABLE 1. Sampling issues: psychological factors that can influence the samples of evidence people use when making judgments.

Psychological phenomenon	Illustration	Suggestion for tackling phenomenon
Attribute substitution	Judgments about attributes that are inaccessible or not easily understood, such as “climate,” may be substituted by more readily accessible attributes, such as “weather.”	Always define terms clearly, even those that are commonplace within the discipline. Invite your audience to reflect carefully on their responses to questions to ensure that the question they answer is the same as the one being asked.
Recency of events in memory	A judgment about the reality of global warming may be more strongly influenced by recent weather events (a cold snap or intense summer heat) because recent events in memory are more salient than those experienced longer ago.	Invite your audience to think about the samples that they are using to draw conclusions. For example, ask them to place recent salient events (e.g., a cold snap) into a wider context, such as the last 10 yr or their whole lives.
Insensitivity to bias in external samples of information	Judgments about the “balance of evidence” in relation to climate science might be unduly influenced by disproportionate media coverage given to those who dispute the basic science.	Remind your audience of the distinction between the debate within the climate science community and the debate as presented via the media. Encourage them not to confuse these separate debates when evaluating the science.
Anchoring on irrelevant information	In conditions of uncertainty, estimations of magnitude (e.g., the concentration of atmospheric CO ₂) can be influenced by the provision of (irrelevant) reference points (e.g., is it below 1000 ppmv vs above 100 ppmv?)	When presenting data identify samples clearly, provide justification for the size of the sample (e.g., a time span of 10 or 100 yr) and choose reference points carefully.

cept), people might instead think about changes in the weather (a concept familiar to everyone).

This confusion can be compounded by the second phenomenon, recency, the finding that events that have occurred more recently are more salient in memory and thus tend to have a disproportionate influence on our judgments (Weber 2006). Thus, when people think about whether the planet is warming, events such as the extreme cold weather of the 2009/10 winter in parts of the Northern Hemisphere may inappropriately affect judgments simply because those events are current and memorable.

Furthermore, the third phenomenon, biases in the external samples of information, can affect memory and judgment processes. For example, if the public read or hear opinions from climate change skeptics about 50% of the time, then this could lead to a bias in the perception of the balance of evidence in the minds of the public (i.e., that the science is only about 50% certain; Moser and Dilling 2004). Failure to accommodate for this bias in the input sample necessarily leads to erroneous judgments about the likelihood of future outcomes (Fiedler 2000).

The fourth sampling phenomenon identified in Table 1 is that of *anchoring*. This is the highly robust finding that the reference point or “anchor value” one uses in describing samples can affect peoples’ judgments and magnitude estimations (Tversky and Kahneman 1974). For example, if you ask an audience to first state whether the current concentration of CO₂ in the atmosphere is greater than 1000 ppmv and then ask for their own estimate of the concentration, they are likely to give a much higher estimate than an audience who are first asked if the concentration is greater than 100 ppmv. When people are uncertain about a true value, given values such as 1000 and 100 are often interpreted as appropriate anchors, which are then insufficiently adjusted away from when making an estimate.

The brief suggestions for tackling these four phenomena, listed in Table 1, all follow a common theme: think carefully about the samples of evidence that you use in presentations, and encourage audiences to reflect on the samples that they are using to draw their conclusions. Sometimes a simple instruction to your audience to consider the opposite conclusion—

that is, engage in some thinking about why an initial hypothesis or preconception might be wrong—can counteract sampling and anchoring biases. By directing their attention to contrary evidence that might not otherwise be considered, people can expand their samples of evidence, thereby making them more representative (Larrick 2004; Strack and Mussweiler 1997).

FRAMING ISSUES: HOW DOES THE WAY EVIDENCE IS PRESENTED AFFECT PERCEPTION AND REACTION?

Framing is a term used to describe how information is presented to convey a particular message or to produce a desired response. In this section, we first describe why choosing the appropriate frame for the science of global warming is as difficult as it is important; then, in Table 2, we present four psychological phenomena relevant to framing.

Climate phenomenon: CO₂—Odorless, colorless, and rare. In the Garnaut Review (an Australian version of the Stern Review), global warming was described as a “diabolical” problem. It is worth reflecting on the reasons for its status as diabolical. Carbon dioxide is a colorless, odorless gas. If it was opaque or smelled like methane, we would never have allowed it to increase to around 390 ppmv, but like most chemicals it becomes a pollutant when increased beyond its normal concentration. It is a natural gas, part of the natural carbon cycle, and essential to plant life. There is no single significant source; it is simply the by-product of most human activities. We measure the impact of increasing CO₂ in terms of radiative forcing. The increase in radiative forcing to date has been about 1.6 W m⁻² because of all forcing and an increase of about 2.64 W m⁻² from the long-lived greenhouse gases. This small number sounds entirely trivial, but 2.64 W m⁻² is about 8,322,502,000 J m⁻² yr⁻¹.

Carbon dioxide is, of course, very rare; it makes up about 0.0384% of the atmosphere by volume. Collapsed to a single layer, it is about 8 m deep. Of course, the amount of something need not be proportional to the impact. For example, cyanide at a level of concentration 100 times lower than the concentration of atmospheric CO₂ in the blood (0.0003%) is fatal. A further problem is that it has taken a century of human emissions to register a problem, and we tend to talk about major problems occurring in, for example, 2050, which is almost an infinitely long period into the future for most human decision making. It also takes decades for the impact of a given level of

atmospheric CO₂ to be realized in temperature, sea level rise, and ice sheet melt.

Finally, if humans dramatically cut emissions, it would take decades before we knew if we had prevented dangerous warming and centuries before natural levels would be realized. Moreover, like the Y2K bug, no consequences could easily be interpreted as “there was never a problem” rather than “we acted to avoid a problem.” If you wanted to create a diabolical problem, it is hard to imagine doing it better than releasing CO₂ into the atmosphere.

Psychological phenomena relevant to framing. The first phenomenon described in Table 2 makes the simple point that the numbers one uses to convey the statistics of global warming can have huge impact on interpretation of the severity of the problem. As we noted in the previous section, a change in the units used to describe radiative forcing can turn a small unimportant sounding number into a very large, more worrying one. Alternate ways of expressing uncertainty can also lead to dramatic differences in interpretation. Several lines of research suggest that numerical information expressed in a frequency format (e.g., 1 out of 100) is more easily interpreted and reasoned with and has a greater influence on judgments than identical information presented as percentages (1%) or probabilities (0.01; e.g., Gigerenzer and Hoffrage 1995; Newell et al. 2008; Slovic et al. 2000; Yamagishi 1997).

The second phenomenon in Table 2 provides insight into a reason why frequency formats (i.e., 1 out of 100) have this effect. Information processing is influenced not only by “cold” cognitive processing but also by “hot” emotional or affective processing (Loewenstein et al. 2001). Global warming is a highly emotive issue, but attaching imagery or affective valence to the particular effects of CO₂ is difficult because it is colorless, odorless, and slow acting. Framing outcomes in terms of numbers like 20 out of 100 (rather than 0.2 or 20%) can engage affective processing because they feel more concrete to individuals than probabilities and percentages (Slovic et al. 2000).

Making outcomes feel more concrete can also help in addressing the third phenomenon in Table 2, the tendency for people to discount the importance of future events relative to those occurring now (Hardisty and Weber 2009; Trope and Liberman 2003; Weber 2006). One explanation for this discounting of the future is that people tend to construe distant and near-future events very differently. Distant future events (such as the prospect of sea level rises in 50 yr)

TABLE 2: Framing issues: psychological factors that can influence the perception of and reactions to evidence.

Psychological phenomenon	Illustration	Suggestion for tackling phenomenon
Psychological nonequivalence of mathematically equivalent information	A chance of 1 in 1000 and 0.1% are mathematically but not psychologically equivalent. Representing the chances of occurrence as frequencies rather than percentages or probabilities can improve the perception and understanding of a complex problem (e.g., the chance that CO ₂ will increase above “safe” levels).	Try to choose one type of numerical format in your presentations (e.g., a frequency format; 1 in 1000) and be consistent in its use throughout. When possible, use simple graphs (e.g., pie charts) to convey numerical information.
Influence of affective processing of information	Information processing does not occur in an emotional vacuum; processing of the affective content of information or the emotional reactions that information evokes contributes strongly to perception and understanding of evidence (e.g., the effect of increased CO ₂)	Use vivid images of global warming (e.g., shrinking glaciers, melting ice sheets) to engage emotional processing, but do so judiciously to avoid emotional numbing or a “despair” response.
Discounting the importance of future events	Judgments about the importance of future events (e.g., perceived impacts of global warming) tend to be discounted relative to events happening in the present.	To mitigate discounting, try to use specific and where possible concrete examples of distant future outcomes (e.g., the appearance of your audience’s local environment in 30 years time or the air quality that their children might face in 2050).
The differential impact of losses and gains	Losses of a given magnitude inflict more psychological “pain” than gains of the same magnitude satisfy. Thus, people tend to avoid outcomes framed as losses more than seek those framed as gains.	Capitalize on “loss aversion” by explaining how actions to mitigate global warming (e.g., insulating one’s home) will lead to the avoidance of large losses (i.e., higher energy bills).

are represented abstractly in terms of general features and the “essence” of an event. In contrast, near-future events (such as the prospect of a river near your house flooding its banks tomorrow) are represented more concretely in terms of the specific contextual and incidental details (e.g., the effect a flood will have on the carpet in your living room; Trope and Liberman 2003; Weber 2006). Encouraging people to think about the possible specific impacts of future events in the context of where they live and how these events might affect their daily routines may have the dual advantage of engaging affective processing and counteracting the tendency to discount the future.

One note of caution: research suggests that people can become “numbed” by overuse of emotional appeals and that they can only worry about a limited set of issues (a “finite pool of worry”; Linville and Fischer 1991; Weber 2006). Thus, although vivid images and concrete outcomes are important when presenting the science, one should use them judiciously. Overuse may have the unintended consequence of

leaving the audience overwhelmed and thus unwilling to take any action on what they perceive as a fait accompli (Moser and Dilling 2004).

The final phenomenon in Table 2 refers to the well-established finding that losses and gains have a very different psychological impact: the pleasure associated with receiving \$500 is less than the “pain” felt when one loses the same amount (Tversky and Kahneman 1981, 1992). This asymmetry in the effect of gains and losses leads people to be “loss averse,” a tendency to be more averse to losses than be attracted by corresponding gains. Recent research indicates that some environmental outcomes are treated similarly to financial ones (Hardisty and Weber 2009); thus, when describing actions to mitigate global warming, messages should focus on the potential to avoid large losses (e.g., high fuel or heating bills) than the corresponding gains (e.g., the savings accrued over time by installing solar hot water).

The suggestions for tackling these framing phenomena are, like those for Table 1, simple to

summarize. To begin with, do not assume that your audience will interpret numerical information and figures as you do (you are unlikely to be speaking to an audience that is as familiar with quantitative relationships as you). Thus, numerical information should be conveyed when possible using an easy-to-understand format (frequency formats have many advantages) combined with straightforward graphs [e.g., pie charts rather than probability density functions (PDFs)] with a minimum of potentially opaque abbreviations such as ppmv or 10⁶. Concrete, specific, and vivid outcomes of global warming should be emphasized and combined with examples that emphasize the avoidance of future losses rather than the receipt of future gains. However, this needs to be done cautiously to avoid emotional numbing.

COMPREHENDING THE PROBLEM AND THE SOLUTION: HOW THE CONSTRUCTION OF MENTAL MODELS AFFECTS THE CONCEPTUAL UNDERSTANDING OF GLOBAL WARMING.

“Mental model” is the term used to describe the collection of partial knowledge and beliefs that people “build” to help understand and make decisions about a given problem or phenomenon (e.g., global warming; cf. Morgan et al. 2002). In this section, we discuss the aspects of global warming that make forming appropriate mental models difficult and make some suggestions for how audiences could be assisted in building a scientifically informed mental model.

Climate phenomenon: The problem and the solution.

The solution to global warming is an economic, engineering, legal, social, and political challenge that is perhaps unprecedented in recent history. It “merely” requires a transition from a carbon-based economy to a non-carbon-based economy. This need is interweaved with a highly complex debate about the level of risk associated with global warming and the scale of solutions required to resolve the problem.

At the heart of the solutions debate is the issue of targets. These are commonly thought about in terms of the amount of warming that is “safe” (e.g., 2°C; Pachauri and Reisinger 2007). We do not know what is safe because we do not know how vulnerable most systems are to warming of 1.5°, 2.0°, 2.5°C, etc. The value 2.0°C is a reasonable target, but it is likely chosen as some balance of safe and “achievable.” Some estimates of the impacts of 2°C of warming include a weakening of the thermohaline circulation, a higher risk of a collapse of the Amazon, or a higher risk of the loss of the Greenland ice sheet (Kriegler et al. 2009).

However, the probability of these abrupt changes is based largely on expert assessment (e.g., Kriegler et al. 2009; Smith et al. 2009), and it is very challenging to quantify such expert assessment in terms of reliability (Dawes et al. 1989).

There is some probability that 2°C of warming is safe. We can estimate the emissions reductions required to avoid 2°C or we can estimate the maximum permissible emissions (integrated over time) that gives us a certain probability of avoiding 2°C (Matthews et al. 2009; Meinshausen et al. 2009). These depend on rates of emissions, rates of transitioning to a new non-carbon economy, climate sensitivity, the probability of abrupt change, and associated feedbacks in some key systems. Most negotiations leading to Copenhagen were talking about cuts in emissions of 10%, 20%, and 30% on 1990 levels, cuts per capita, or increasing the efficiency of the carbon economy. None of these actually matter: it is the actual concentration of CO₂ in the atmosphere that matters and how fast we can get the actual concentrations down to a level that we consider safe at some level of agreed probability.

Achieving this goal is complex. The time scales of emissions are important. Specifically, discussions about emission reductions typically use different start dates, different rates of emission reductions, or total permissible emissions. There are arguments about whether 2°C is safe. There are arguments about the safe level of equilibrated CO₂, what CO₂ can peak at, and how fast it has to be reduced. Of course, all arguments are complicated by questions of equity, wrapped in rhetoric from some that there is not really a problem and from others that there is an unmanageable catastrophe just around the corner. There is also a position that cutting emissions threatens economic growth and that we therefore need to maintain emissions to be able to afford to remedy the impacts of emissions in the future.

All these positions may actually be consistent with the best climate science, provided you are willing to “cherry pick” that part of a PDF that suits your belief. The IPCC Fourth Assessment Report provides the PDFs of global warming in Fig. 6 of Alley et al. (2007; the figure can be viewed online at www.ipcc.ch/publications_and_data/ar4/wgl/en/spmsspmp-projections-of.html). At the bottom of the PDF of global warming by 2100, assuming a very low climate sensitivity and very low emissions, is a value close to 0°C. This would not be catastrophic, but it has a very low probability (perhaps zero) of being achieved both in terms of climate sensitivity and emissions. At the very top end of the PDF with an approximately

equivalent probability is warming exceeding 8°C. Rather than cherry pick particular points in this distribution, communicators of the science need to be very clear about the probabilities of the particular future that they are predicting. Claims that Earth will warm negligibly and claims that it will warm catastrophically could both be considered consistent with the available science; however, those proposing these two extreme positions should take care to emphasize the near-zero probability of these outcomes.

Psychological phenomena relevant to comprehending the problem and the solution. Table 3 highlights two relevant psychological phenomena. The first is simply the notion of a mental model and how it is used to organize and evaluate information. As the previous section illustrates, the mental model that is required to represent all of the variables and uncertainties involved in assessing the threat of global warming is very complex. By way of analogy, we might agree that the specific details of the causal link between smoking and lung cancer are complicated, but we are able to grasp that inhaling carcinogenic material increases our chances of lung cancer. For many of us, our fragmentary knowledge of the links between cancer and smoking is sufficient to represent the risks appropriately. In contrast, understanding how and why an increase in atmospheric CO₂ leads to warming and how and what we do (as individuals and communities) affects the composition of the atmosphere is much harder.

Sterman and Booth Sweeney (2007; see also Sterman 2008) provided some evidence on exactly how difficult establishing the correct mental model can be. They gave Massachusetts Institute of Technology (MIT) graduate students an excerpt of the Summary for Policymakers from the IPCC Third Assessment Report, which described the relationships among greenhouse gases, atmospheric concentrations, and global mean temperatures. They then asked students first to estimate the future net removal of CO₂ from the atmosphere and then to sketch on graphs the CO₂ anthropogenic emissions trajectory required to stabilize atmospheric CO₂. In 84% of cases, participants drew emissions trajectories that violated basic principles of accumulation. The trajectories reflected a mental model in which atmospheric CO₂ could be stabilized even if emissions continuously exceeded removal. The authors provided an analogy that this is equivalent to assuming that a bathtub continuously filled more quickly than it drains will not overflow.

The difficulty in establishing the correct mental model can be compounded by the second phenomenon listed in Table 3, the tendency for humans to rely on confirmatory evidence. Many studies have shown that when people test hypotheses they tend to adopt a “positive” testing strategy, seeking evidence that supports rather than challenges an initial hypothesis. Although adopting such a testing strategy is not necessarily bad practice (Klayman and

TABLE 3. Comprehending the solution: psychological factors that can influence the understanding of global warming.

Psychological phenomenon	Illustration	Suggestion for tackling phenomenon
Construction of mental models for representing problems	To facilitate understanding of a problem (e.g., the threat of global warming), people tend to assemble relevant but often fragmentary prior knowledge and beliefs into a “mental model.” This model is then used to draw conclusions, assess risks, and determine a course of action.	Try to gauge an audience’s mental model via reactions to initial questions or presented information and then tailor your message. Establish basic concepts and lay the foundations for understanding the causes and effects of global warming. Simple diagrams and analogies (e.g., the bathtub; see text) should aid this process.
Reliance on confirmatory evidence	When testing hypotheses (e.g., that human-induced global warming is a myth), people often rely on “positive-testing strategies,” asking questions that are expected to result in a “yes” response given the truth of a working hypothesis. This can lead to a “confirmation bias” if the hypothesis is not properly evaluated.	Invite the audience to think about why a working hypothesis might be incorrect. Emphasize that all evidence, positive or negative, needs to be evaluated in the context of the hypothesis [e.g., two consecutive years that have shown cooling (positive evidence for a myth hypothesis) in the context of a warming trend over 50 yr (negative evidence)].

Ha 1987; McKenzie 2004), in some situations it can result in inappropriately high confidence in a given hypothesis, a phenomenon described as the “confirmation bias” (Wason 1960).

The relevance of confirmation bias to the construction of a mental model representing the risks of global warming is clear; if people’s testing strategies make it unlikely that they come across disconfirmatory evidence and they fail to take their strategy into account when evaluating their hypothesis, the perception of the problem may be subsequently biased. The tendency for people to downplay evidence that is inconsistent with their working hypothesis or interpret ambiguous evidence in ways that give their hypothesis the benefit of the doubt (e.g., Klayman 1995) could also contribute to a failure to construct appropriate mental models.

Tackling these phenomena entails patience, education, and careful framing. Misinformation, the occasional cold day, and the misquoting of science allow a large fraction of the public and policy makers to retain their existing mental models. Knowing your audience and gauging its members’ mental models is an important first step in tailoring presentation of the science.

CONSENSUS BUILDING: HOW GROUP DYNAMICS CAN AFFECT THE FORMULATION OF THE GLOBAL WARMING MESSAGE.

This penultimate section touches briefly on factors affecting how the climate science community might improve the formulation of the message before disseminating it to the wider community. Fischhoff, writing presciently in 1981, noted that the limitations of climate science (in terms of the certainties placed on predictions) could reach lay audiences via explicit statements of uncertainties, which entail the types of problems discussed in the preceding sections, and the observation of disagreement among experts. In the latter case, Fischhoff (1981, p. 178) worried about the following:

Unless the audience has an appreciation of the naturally disputative and accretive character of science, its resolution of the conflict may not be a balanced and informed weighting of the sides. Alternative resolutions are doubting the probity of the disputants, siding with the most assertive (or colorful or optimistic or certain), or deciding that “anything goes” and that “my guess is as good as yours.”

The irony of the situation almost 30 yr later is that there is little genuine disagreement among experts

about the basic science of global warming, but the desire for “balanced” media coverage of the debate appears to have led to exactly the outcome Fischhoff feared (Moser and Dilling 2004): A recent poll found that 40% of surveyed Americans believe that there is “a lot of disagreement” among scientists about whether global warming is happening (Leiserowitz et al. 2010).

This outcome is deeply confronting to the climate science community; the climate scientists use the scientific method to reject wrong science. Once wrong science has been rejected, the debate moves on. Unfortunately the scientific method is a scientific method and, as Fischhoff noted, it is not intuitive to many members of the general public or politicians who are more familiar with arguments won by clever debate or oratory. How to maintain the scientific method and convey the urgency of the message without resorting to public advocacy is a tricky path to follow (cf. Fischhoff 2007).

One route to remedying this problem is ensuring that climate scientists emphasize the transparent and unbiased nature of their discussions and evaluation of evidence. A starting point is to ensure that, in meetings where consensus between experts is the goal, steps are taken to encourage optimal discussion of information.

Climate community phenomenon: The experts in a room problem. The IPCC or equivalent assessments of the state of the science of climate and global warming are phenomenally rigorous. A key part of the process is lead author meetings where around 10 experts (lead authors) meet to discuss specific issues, specific reviewers’ comments, or contentious pieces of science. A consensus is reached, and this consensus, provided it can be fully supported by the literature, is reported.

One issue that might contribute to problems in reaching a consensus is bias in the literature we read. Very high impact journals such as *Nature and Science* publish the latest high impact science. If experts source their perspective from journals such as *Nature and Science* they could form a different opinion than if they sourced their perspective from the *Journal of Climate*.

Psychology factors affecting the process and perception of consensus building. Table 4 presents two psychological phenomena relevant to consensus building and group dynamics. The first, biased information pooling, refers to a process that can occur within a group attempting to reach a consensus. Pooling

TABLE 4. Consensus building: psychological factors that can influence the process and public perception of how a consensus about climate science is reached.

Psychological phenomenon	Illustration	Suggestion for improving process
Biased information pooling in group discussion	The effective pooling of information in group discussions can fail to occur because discussion is dominated by information that is shared by members prior to discussion and by information that is consistent with members' prior beliefs and preferences.	Allowing sufficient discussion time for "unshared" information to be aired can counteract biased pooling, as can having at least one group member who is an advocate of the position favored by unshared information.
Groupthink	A label to describe defective decision making that can arise from highly cohesive, insular groups that have directed leadership, a lack of procedures for search and appraisal of information, and low confidence in the ability to find an alternative solution to the one favored by the leader.	To avoid public perception that the climate science community has been beset by "groupthink," steer clear of an us (believers) vs them (deniers) portrayal in your presentations of the scientific evidence.

information should lead to improved decisions, provided information is shared effectively. However, research indicates that effective pooling often fails to occur, because group discussion is dominated by information that members hold in common prior to discussion and by information that is consistent with members' prior beliefs and preferences (Stasser and Titus 1985; see also the positive testing strategy described earlier). This can have the deleterious effect of perpetuating rather than correcting preexisting biases. Thus, if experts' initial perspectives are biased in idiosyncratic ways (perhaps because of the over-weighting of information from high impact sources), these biases will not necessarily be eroded through discussion.

The second phenomenon in Table 4 is "groupthink," a term coined by Janis (1972) that has become a catch-all label for defective decision making that can arise from groups with dysfunctional dynamics (Fuller and Aldag 1998). We are not asserting that groupthink has taken hold of the climate science community; this is highly unlikely because there is too much to be gained for individuals who provide rigorous and scientifically defensible alternative ideas. However, the public perception and media portrayal of the community as being unwilling to listen to dissenters combined with an unassailable belief in the correctness of their position (antecedent conditions of groupthink) need to be addressed.

Table 4 notes two brief suggestions for improving the process and perception of consensus building. On the process side, other techniques for improving effective sharing of information in discussion include ensuring access to all relevant informational records

during discussion, separating the process into a search for information followed by the integration of that information, and assigning group members to be responsible for specific categories of information and making sure that knowledge of who knows what is shared among group members (Kerr and Tindale 2004). On the perception side, climate scientists must strive to be trusted, credible sources of information without, if possible, engaging in advocacy and divisive rhetoric. In short, try to let the science speak for itself in a clear, comprehensible manner (Fischhoff 2007).

CONCLUDING REMARKS AND SUMMARY.

Simply presenting the facts and figures about global warming has failed to convince large portions of the general public, journalists, and policy makers about the scale of the problem and the urgency of required action. From a psychologist's perspective this disconnect is not surprising. Facts and figures need to be tailored to fit with the way in which humans' process information, deal with uncertainty, and form attitudes and opinions. By combining our efforts, climate scientists and psychologists can provide not just the science but the tools for communicating and interpreting the science (Sterman 2008).

We are not suggesting that psychology has all the answers when it comes to convincing the public about the need for action. Stern (1992) pointed out that many variables outside the scope of psychological theory (e.g., socio-demographic status, geographic context, institutional arrangements) will all have a significant impact on the willingness to engage with the science and commit to action. Global warming is also an incredibly politicized issue; thus, many of

the pronouncements on the problem and the solution are subjected to considerable political “spin” that goes beyond the scientific domain in which climate scientists feel comfortable. Psychology can provide some insight into how these issues can be addressed, but other branches of social science such as sociology and social policy also have much to offer (Fischhoff 2007; Stern 1992).

In summary, our review highlights four classes of psychological phenomena that provide food for thought to the climate scientist wishing to disseminate findings to the wider community: 1) sampling issues: clarity about the source and representativeness of samples of evidence that your audience and you are using to form inferences and draw conclusions; 2) framing issues: methods for presenting science should engage cognitive and emotional processing, in a balanced manner, and try to make distant future outcomes concrete; 3) comprehending the problem and solution: communicators should take into account the “mental model” held by members of their audience and tailor presentations accordingly; and 4) consensus building: the process and public perception of reaching a consensus about the science needs to be effective, transparent, and objective.

As we noted at the outset, our treatment of these issues has been brief and our suggestions simple; many of the papers we have cited contain more detailed empirical demonstrations of the phenomena along with specific strategies and protocols for addressing them (see Further Reading for more information). Our hope is that this overview of the essence of what psychology can offer will precipitate further much needed collaboration between our two communities and ultimately lead to the message of global warming being heard and heeded.

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