6

Science Communication

Countering Skepticism and Delivering Information Clearly

> Errors and biases arising from the mental models and heuristics we use to evaluate risks and make decisions in complex systems. . . arise not only in the context of unfamiliar systems like the climate but also in familiar, everyday contexts such as compound interest or filling a bathtub. Therefore they cannot be remedied merely by providing more information about the climate, but require different kinds of communication.
>
> John Sterman

Even though preexisting worldviews and values play a large role in the level of epistemic skepticism toward the findings of climate science held by individuals and groups, facts – and how those facts are presented – do shape people's understanding and acceptance of those findings.[1] Based on that recognition, a number of researchers have investigated what specific modes of communicating those often complex scientific facts are likely to be most effective at promoting belief in the inconvenient and often frightening realities of climate change.[2] They have explored ways in which scientists, activists, journalists, policy makers, and others concerned about global heating can communicate climate science findings most effectively and persuasively to the general public. This chapter illustrates the value of science communication on climate change by focusing on five strategies: clarifying the mechanism behind global heating, emphasizing the consensus among climate scientists, counteracting misinformation about climate change, overcoming the challenge of uncertainty, and effectively communicating information visually.

Clarifying the Mechanism behind Global Heating

Although climate science is a vast field, only a subset of that information is probably vital to understanding global heating and changing skeptics' minds.

As suggested in Chapter 1, one piece of information that is especially important to this understanding is a **mechanistic explanation** of the greenhouse effect – an explanation of how human activity causes a rise in CO_2 levels that in turn causes global heating.

To test the hypothesis that teaching people about the chemical-physical mechanism of the greenhouse effect would make them more likely to believe in human-caused global heating, two psychologists conducted a series of experiments.[3] The results of their first experiment, a survey of a few hundred visitors to San Diego's parks, found that although 80 percent of the study participants accepted that global heating was occurring and 77 percent accepted that it was human-caused, only 3 percent could name the greenhouse effect and only 1 percent were able to articulate a key aspect of that theory: the difference between infrared energy and sunlight. They also found that those who demonstrated more knowledge about the mechanisms behind global heating were most likely to accept that it was happening (a weak correlation of $r=0.22$) and that it was human-caused ($r=0.17$).

In a second experiment, which included nearly a hundred students from Berkeley and a smaller sample from the University of Texas, participants were again asked about their acceptance of global heating and their level of knowledge about the greenhouse effect. Unlike the first experiment, however, they were then asked to read a 400-word explanation of the greenhouse effect and retested to see if their attitudes toward global heating and knowledge of the mechanism of heating had changed. The researchers again found that almost none of the participants had knowledge of the greenhouse effect before reading the explanation, but that after reading the explanation, 59 percent correctly stated that the Earth emits infrared light, and a good proportion now stated knowledge of other aspects of the mechanism of global heating, and their acceptance of global heating increased.

To test the durability of the impact of this brief intervention, a third experiment, also conducted with undergraduates, followed the same format but retested the participants much later, with an average delay of 18.5 days. The results showed that this brief learning experience increased participants' belief in global heating and that knowledge of the mechanism behind this effect lasted at least several weeks. Two following experiments showed similar effects with even longer delays.

Averaged across the experiments the researchers showed that these brief interventions increased mechanistic knowledge by 28 percent and increased acceptance that global heating is happening by 9 percent upon delayed retesting. Although these changes in belief were relatively modest and reflect self-reported beliefs and intentions rather than actual changes in behavior, these

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and several other published studies do suggest that teaching the mechanisms behind global heating can make a difference, even among politically conservative people.[4]

Another mechanism that is important to understanding global heating is the interaction between carbon emissions and carbon sink removals of atmospheric CO_2. As discussed earlier in this book, the level of global heating is determined by the concentration of CO_2 in the atmosphere, which can last for thousands of years from the time of emission and is increased by continued burning of fossil fuels. Although some of this CO_2 is taken up by the carbon sinks in the land and the ocean, those can absorb only about half the current concentration and they take time to work. As a result, slight reductions in CO_2 emissions will not immediately reduce atmospheric concentrations but simply slow the rate at which they are added to the atmosphere; only by ceasing or substantially reducing new CO_2 emissions will carbon sinks be able to remove enough existing CO_2 for concentrations to actually decrease. This is called the **stock-and-flow problem**, which can be explained with a bathtub analogy: the level of water in a bathtub will continue to rise as long as the flow from the faucet exceeds the flow out from the drain and will go down only when the flow from the faucet decreases enough for the drain to remove more water than is flowing in.[5] The more dramatic the decrease in flow from the faucet, the faster the water level will go down.

As simple as this principle may appear, it can be a difficult concept for people to understand. As demonstrated by the results of a study shown in Figure 6.1, even people with math and engineering training often incorrectly believe that we can keep CO_2 levels from increasing by simply stabilizing rather than drastically reducing our current emissions. That figure shows that when participants were asked to draw how emissions and removals would proceed after the year 2000 to match a stabilization of atmospheric CO_2 levels by about 2050, they correctly drew removals as a constant level, but they also drew emissions as stable, when emissions would actually need to dramatically decrease. This misunderstanding of the mechanisms that produce global heating is not a trivial matter, as it works against a wide recognition of the seriousness and size of the problem and leads many people to think that we can afford to wait to see how bad climate change actually gets before taking concerted action. (Incidentally, it explains why atmospheric CO_2 kept increasing during the pandemic in the year 2020 even though emissions were cut about 6 percent globally).

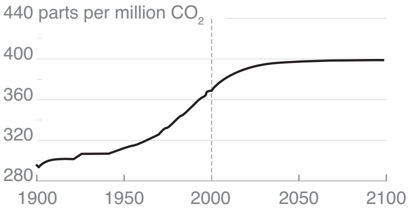
The work mentioned above on communicating the greenhouse effect and the stock-and-flow problem are both examples of providing mechanistic information in the climate science domain. Why such mechanistic explanations might be effective has been better explored in the domain of health

Figure 6.1

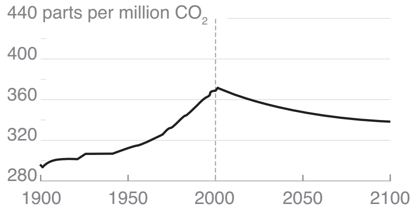
When thinking about reductions of atmospheric CO_2, people don't apply the basic stock-and-flow (bathtub) analogy, and so dramatically underestimate how much reduction is needed

(A) Scenarios with rising and falling CO_2

Subjects were asked to consider a scenario in which **atmospheric CO_2 gradually rises to 400 ppm**, then stabilizes by the year 2100:

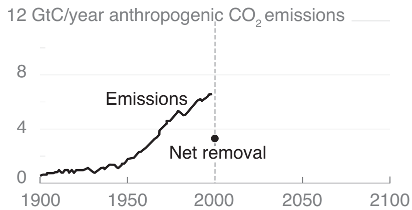


Alternatively, others were asked to consider a scenario where **atmospheric CO_2 gradually falls to 340 ppm**, then stabilizes by 2100:



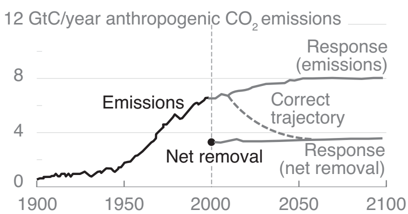
(B) Current emissions and removal levels

Given the scenarios above, both sets of subjects were shown the anthropogenic CO_2 emissions from 1900 to 2000 and current net removal of CO_2 from the atmosphere by natural processes were provided. They were then asked to sketch their estimate of (a) future anthropogenic CO_2 emissions and (b) future net CO_2 removal.

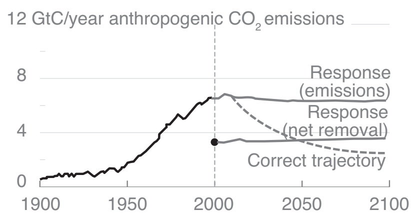


(C) Estimates

Although a scenario of unchanging emissions requires that emissions eventually equalize with removals (E = R), the subjects drew paths where they continued to outpace removals (E > R).



Although a scenario of declining emissions requires that emissions eventually dip below removals (E < R), the subjects drew paths where they continued to outpace removals (E > R).



Adapted from Sterman JD and Sweeney LB. Climatic Change (2007) 80:213–238 DOI 10.1007/s10584-006-9107-5

interventions. One such study found that children who received biologically based mechanistic knowledge about the spread of viruses reasoned better about viral survival and were better at identifying risky and preventative behaviors than children who simply received information about the differences in

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symptoms between colds and flu and a list of behaviors to follow or avoid. Based on these and similar results regarding antibiotic resistance, vaccination, and nutrition, researchers Kara Weisman and Ellen Markman have theorized that mechanistic or theory-based explanations lead to more behavioral change because they focus on the underlying causal framework rather than superficial details and make people's understanding more robust to misinformation.[6] Such findings suggest that mechanistic explanations are special and that providing the public with more mechanistic knowledge about the greenhouse effect, the stock-and-flow relationship of atmospheric CO_2, and other key aspects of climate science and extreme weather attribution is likely to play a key role in counteracting skepticism or apathy about global heating and encouraging the public to demand more serious action to combat it.

Emphasizing the Consensus among Climate Scientists

That human activity is responsible for the global heating we are currently experiencing is no longer a source of scientific debate among climate scientists, as discussed in the previous chapters and reflected in the IPCC 2021 declaration that the evidence for human-caused global heating is *unequivocal*. Yet, years earlier Republican strategist Frank Luntz, recognizing that "[s]hould the public come to believe that the scientific issues are settled, their views about global warming will change accordingly," recommended that "[t]herefore, you need to continue to make the lack of scientific certainty a primary issue in the debate."[7] One manifestation of the vast organized disinformation campaign that followed is that, from 2007 to 2010, the most common argument in conservative op-eds on climate change was that there was no consensus among scientists that it was human-caused.[8]

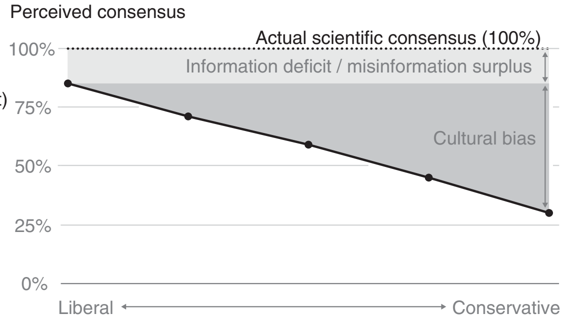
This vast, organized disinformation effort has been stunningly successful: a 2014 survey of twenty nations, for example, found the USA had the lowest levels of belief in this expert consensus, and a 2016 study found that even many US science teachers were unaware of it.[9] As of 2020, only 55 percent of surveyed US adults believed that this consensus existed.[10] As shown in Figure 6.2, research has found that this **consensus gap** – the difference between the actual scientific consensus and people's belief in it – varies in degree between politically liberal and conservative respondents. The fact that it is greatest among the most politically conservative respondents suggests that it is influenced by cultural factors, but that it exists among even the most liberal respondents suggests that it is also influenced by lack of knowledge or misinformation.[11]

Figure 6.2

The gap between beliefs about scientific consensus and the actual consensus relates to both misinformation and culture

For liberals, the perceived consensus in 2020 was 85 percent. The difference between this and the actual scientific consensus (100 percent) is mostly or entirely due to an information deficit or a surplus of misinformation.

For conservatives, the perceived consensus is only about 30 percent, due to both an information deficit and a cultural bias (owing to political ideology and other factors, as discussed in Chapter 5)



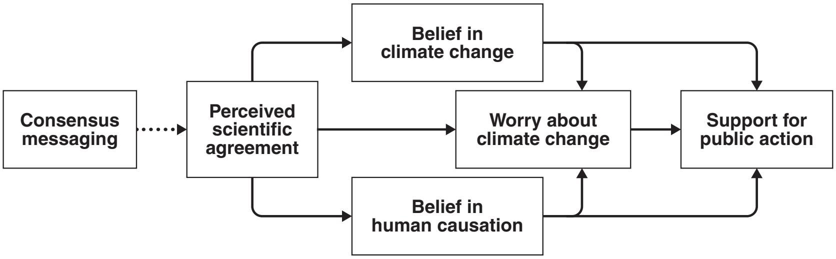
Adapted from a graphic in the consensus handbook, http://www.climatechangecommunication.org/all/consensus-handbook/. Updated with 2020 data from the Yale Program on Climate Change Communication. That set the consensus at 97%, however the IPCC 2021 report, backed by governments, calls anthropogenic global heating "unequivocal" which we take to mean 100% consensus.

The prevalence of misinformation on this point prompted a research group led by Sander van der Linden to investigate whether providing people with accurate information about the near-total scientific consensus on climate change could not only change their beliefs regarding that point but also serve as a gateway to develop accurate beliefs about climate change more generally, a theory they termed the **Gateway Belief Model** (Figure 6.3).[12] In a series of studies, including a 2016 large-scale replication study of more than 6,000 US adults nationwide, participants were asked to use a sliding scale to indicate their perception of the level of *scientific consensus* regarding global heating their level of belief in the reality of *global warming* and its *human causation*, and their level of *worry about global warming* and of *support for action on global warming*.[13] One group of participants was then asked to read a statement that "97 percent of climate scientists have concluded that human-caused global warming is happening," while other participants were either given no information or completed a neutral word-sorting task, after which all participants were asked to answer the same five survey questions again. The results demonstrated that those who were provided with information about the consensus among climate scientists reported an increase in belief in the level of consensus, and increased beliefs in global warming, human causation, worry about global warming, and support for action than participants who received no intervention. The same researchers later found that the impact of consensus information on the treatment group was even greater when video rather than

Figure 6.3

Belief in scientific consensus can be a "gateway" to other beliefs

Psychology experiments in large samples of participants measure people's perceived sense of the scientific agreement, their belief in climate change, human causation, and other variables. An information manipulation is then done to tell people about the consensus (i.e. consensus messaging). A statistical method called structural equation modeling suggests that such consensus messaging information then "affects" the other variables, leading to increased belief and support for public action.



Adapted from van der linden et al. Journal of Environmental Psychology, 62, (2019), 49-58.

text was used to highlight the consensus and that the effects of that perceived consensus were still evident six months later. [14]

Although other researchers have pointed to the limitations of such studies of the effectiveness of communications conducted in the lab rather than in the real world,[15] the results of these large-scale and replicated studies do suggest that consensus messaging can positively affect beliefs regarding climate change. In another example, researchers who showed participants a video clip in which comedian John Oliver filled his stage with a hundred people, three of whom were identified as contrarian scientists and the rest as mainstream scientists, found that this striking visual representation of how absurd it is to believe there is no consensus on climate change increased those participants' belief in that consensus.[16] Such evidence suggests that the consensus gap, which narrowed more than 20 percent between 2010 and 2020,[17] could be reduced even further by efforts among educators, journalists, political leaders, and activists to provide the public with more information about the overwhelming scientific consensus among climate scientists that global heating is the result of human action rather than natural variation.

Counteracting Misinformation on Climate Change

Another way in which science communication can help counter skepticism regarding climate change is to correct specific misinformation. One way to do

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this is to "inoculate" people against such information by refuting it in advance, which is sometimes also called **prebunking**. Just as vaccines employ weakened doses of pathogens to trigger the production of antibodies to protect people from later infection, inoculation against misinformation exposes people to weakened forms of misinformation so they can recognize and reject the real thing later. This inoculation typically involves two components: a forewarning to participants to expect a threat, and the pre-emptive provision of refutational information.

The way this works is illustrated by another study by the van der Linden group that attempted to use inoculation against the Global Warming Petition Project, one of the most potent misinformation campaigns against the scientific consensus discussed in the previous section.[18] The Global Warming Petition Project is an online petition started in 1998 that claims to have obtained the signatures of more than 31,000 US scientists in support of its declaration that human activity is not disrupting the climate.[19] As others have pointed out, 99.9 percent of the signatories were not climate scientists, many were not scientists at all, and many were not even actual people but had names such as "Spice Girls." And even if all 31,000 signers were actually scientists, that number would amount to only 0.3 percent of the ten million people in the USA who have a science degree. Nonetheless, a 2016 analysis found that the petition was frequently cited as evidence in social media posts regarding the supposed "climate myth."[20] The van der Linden group's study of more than 2,000 US participants found that providing participants with just a message conveying the scientific consensus message increased their perception of consensus by about 20 percent; that exposing participants to the Global Warming Petition neutralized the positive impact of subsequently presenting them with the consensus information; but that pre-emptively warning participants about politically motivated attempts to spread misinformation protected their perception of the existing consensus when they were later presented with the petition misinformation.[21]

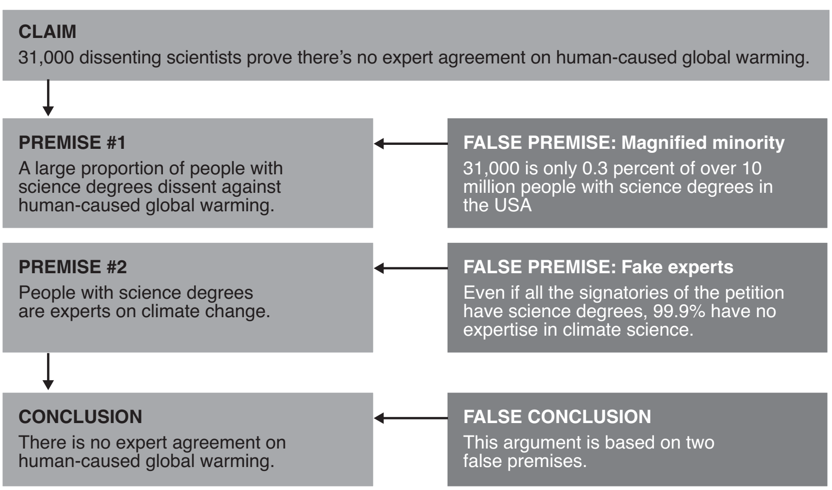
Based on these results, the study authors recommended two main strategies that science communicators can employ to help people contend with the misinformation they are likely to encounter in real-world conditions. The first of these is to accompany communications about the scientific consensus on human-caused climate change with information forewarning readers or viewers that politically motivated actors seek to undermine belief in this established science. The second is to help the public build what they call a "cognitive repertoire" of information about disinformation campaigns in general, which could, for example, be built into a general school curriculum. (In 2019, for instance, Italy mandated that students of all ages receive thirty-three hours of climate change–related education per year.)[22] As these suggestions indicate, to effectively counter misinformation of various kinds, such education would need to not only communicate the physical facts of climate change but also address the political motivations of the fossil fuel industry and its allies and the history and practice of misinformation campaigns. For example, much of the current misinformation campaign has shifted its efforts from sowing doubt about the scientific consensus or facts of global heating to **greenwashing**, in which business-as-usual practices are represented as forms of climate action, such as the strategy of branding fracked methane gas as "natural" gas. Another strategy that is useful for prebunking, which could be part of a general education curriculum, is to teach people to do lateral reading – consulting other sources to examine the reliability of a piece of information or the credibility of the source.[23]

In addition to prebunking or inoculation, people can also be taught how to **debunk** misinformation – to counter specific misinformation by pulling apart its mistaken premises and conclusions, as in the specific example of the Global Warming Petition Project's central claim given in Figure 6.4.[24] Such efforts could be helped by equipping people with basic information on global heating

Figure 6.4

Example of how to debunk a climate myth

The structure of the claim that there is no global warming based on the Global Warming Petition Project. Premise 1 is seen to be false based on simple logic. Premise 2 is seen to be false by inspecting the names of signers.



Adapted from https://www.climatechangecommunication.org/wp-content/uploads/2018/03/Consensus_Handbook-1.pdf

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including not only the main mechanism of global heating as discussed earlier, but also the facts in Global Heating 1-2-3 we saw in Chapter 1, including specific facts such as the irradiance of the Sun has actually decreased somewhat in recent decades, which could be used to debunk claims that global heating is caused by sun spots. Even if someone being confronted by such misinformation does not currently have those facts within immediate recall, being aware of the wishful thinking and oversimplification that often accompanies such denials regarding global heating can at least help people think twice before accepting questionable claims.

Contending with misinformation is, of course, a skill that is important in many domains of life beyond climate change. Misinformation has now become a global problem of huge proportions, as demonstrated by recent misinformation campaigns targeted toward the Brexit campaign in the UK, 2020 election results in the USA, and Covid-19 protocols and vaccines. In recognition of this problem, several of the technology companies whose platforms have been used to spread such misinformation have begun to try to do something to prevent it, such as Facebook's collaborating with third-party fact-checking agencies to flag misleading posts and issue corrections and Twitter's using algorithms to label some tweets as misleading or disputed. Stirred into action by the health and political impacts of such misinformation efforts, the United Nations has launched a platform called "Verified," which is intended to build a global base of volunteers to debunk misinformation and to spread fact-checking content. Yet much remains to be done – as one recent research study on misinformation concluded, "the full potential of applying insights from psychology to tackle the spread of misinformation remains largely untapped."[25]

Misinformation can also be countered by making critical thinking and reasoned decision-making one of the primary objectives of education. As several researchers examining this problem have recommended, students can be taught how to directly address the arguments of climate change dissenters, be assigned texts that address these misconceptions explicitly, and be taught the process and methods of argumentation.[26]

Overcoming the Challenge of Uncertainty

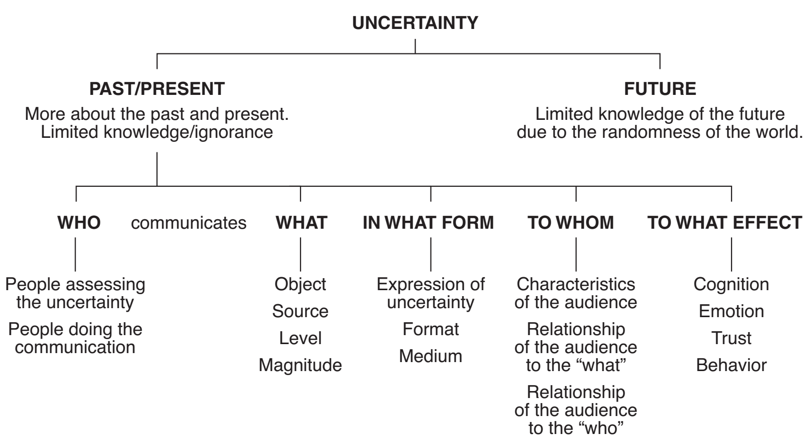
One dilemma facing climate science communicators is that communicating accurately about global heating and its likely effects necessarily means talking in terms of probabilities and likelihoods rather than certainties. Scientific findings and predictions always contain some level of uncertainty and evolve over time as conditions change, new information is uncovered, and new techniques of investigation are developed. Scientists rightfully view this uncertainty as one of science's greatest strengths, as it discourages error and complacency and spurs them to continually ask new questions and engage in further investigation and research. Nonscientists, however, sometimes confuse this inherent uncertainty with unreliability, and climate scientists thus worry that accurately conveying limits on the certainty of their conclusions will sow confusion, undermine the public's confidence, and be exploited by climate deniers.

As Figure 6.5 illustrates, science communicators must find effective and accurate ways to communicate uncertainty from what already happened, and uncertainty about what will happen. Focusing on past uncertainty, it can be affected by a variety of factors, including *who* is communicating *what*, *in what form*, *to whom*, and *to what effect*. An article published in the National Academy of Sciences tested the "in what form" variety by communicating uncertainty about the magnitude of a number, and how this affected participants' trust in that number and in the source that was doing the communication.[27] In the first in a series of experiments, the authors asked more than 1,000 participants to read a short statement about global temperature: "An official report stated that between 1880 and 2012, the Earth's average global surface temperature has increased by an estimated 0.85°C." One group of

Figure 6.5

Science communication has to grapple with the problem of conveying uncertainty.

There is uncertainty about the past/present and also about the future. By being aware of the subcomponents of uncertainty (i.e. who, what, in what form, to whom and to what effect) science communications can more effectively tailor their messages.



Adapted from van der Bles et al. 2019 Royal Society: Open Science. https://royalsocietypublishing.org/doi/10.1098/rsos.181870

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participants received no further information about that statement, constituting the control condition with no uncertainty. A second group, which constituted the numeric uncertainty condition, was also given a numerical range appended to the estimated number: "with a minimum of 0.65°C and a maximum of 1.06°C." A third group, constituting the verbal uncertainty condition, were given a verbal statement appended to the estimated number: "the report states that there is some uncertainty around this estimate, it could be somewhat higher or lower." After reading the statement, participants were asked to recall the specific temperature and to answer questions about how reliable they perceived the number to be and whether they thought the writers of the report were trustworthy. As shown in Figure 6.6, this research found that, as one

Figure 6.6

Communicating uncertainty around data can be done in a way that preserves audience confidence in the data itself

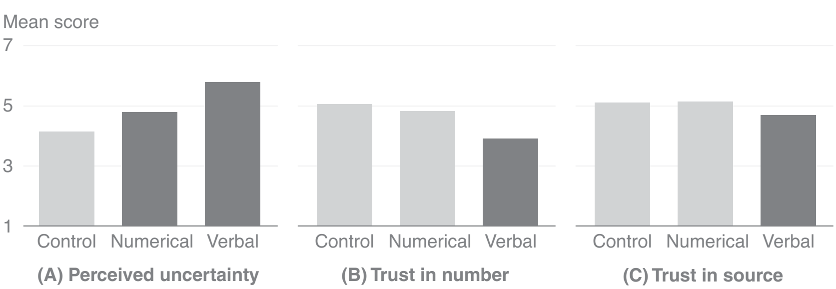
Three different groups were presented with a short text (e.g. regarding the Earth's average global surface temperature). For one group the text did not present any uncertainty (just the estimate, Control), while for the other two it was expressed as a numerical range (Numerical) or a written statement (Verbal).

Example control statement: "Between 1880 and 2012, the Earth's average global surface temperature has increased by an estimated 0.85°C."

Example numerical uncertainty statement: "Between 1880 and 2012, the Earth's average global surface temperature has increased by an estimated 0.85°C, with a minimum of 0.65°C and a maximum of 1.06°C."

Example verbal uncertainty statement: "Between 1880 and 2012, the Earth's average global surface temperature has increased by an estimated 0.85°C. The report states that there is some uncertainty around this estimate, it could be somewhat higher or lower."

Participants were tasked to score how much uncertainty they perceived, how much they trusted the original estimate, and how much they trusted the source of information. Conveying numeric and verbal uncertainty *did* lead to significantly greater perceived uncertainty than control (A, dark bars). Decreases in trust in the estimate (trust in number, B) and in those communicating it (trust in source, C) were small and only significant when the uncertainty was communicated verbally.



Adapted from Anne Marthe van der Bles, Sander van der Linden, Alexandra L. J. Freeman, David J. Spiegelhalter, The effects of communicating uncertainty on public trust in facts and numbers. *Proceedings of the National Academy of Sciences*. Apr 2020, 117 (14) 7672-7683; DOI: 10.1073/pnas.1913678117.

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might expect, people did perceive the statement as being more uncertain when uncertainty was communicated, but the important finding was that their degree of trust in the actual number and in the source of information was not decremented when that uncertainty was expressed as a numerical range compared to when it was a verbal statement. Other experiments in the same study showed similar results, with the final one, Experiment 5, running a field experiment with the BBC website in which the researchers showed that the results could be generalized to some extent, beyond the online laboratory to the real world. These results led the authors to recommend communicating uncertainty in the form of an estimate followed by a numerical range, a practice that has been adopted in recent IPCC reports.

Another set of researchers conducted a similar experiment related to future uncertainty by asking a representative sample of US adults to read about predictions of the anticipated impact of global heating on sea-level rise.[28] One group of participants, serving as a control group, read that statement without any expression of uncertainty. For another set of participants, the **bounded uncertainty** group (akin to the numerical uncertainty group above), the uncertainty inherent in that statement was expressed as a range: "global warming will cause sea level to rise about four feet, but it could be as little as one foot or as much as seven feet." For a third set of participants, the **irreducible uncertainty** group (akin to the verbal uncertainty group above), the uncertainty was expressed verbally in terms of impacts, such as "storms induced by global warming could influence sea level in unpredictable ways." The results showed that, much as in the research described above, participants who were given the bounded uncertainty estimates reported increased trust in the scientists, which in turn increased their acceptance of the statement to an even higher level than that found among the control group, suggesting that participants found the science more trustworthy when it expressed uncertainty. That effect was reversed, however, among participants in the irreducible uncertainty group, who trusted the scientists less than those in the control group, which also reduced their acceptance of the message. These results indicate that differences in how future uncertainty is expressed can affect how scientists are perceived and the way their messages are received – in particular, audiences are willing to accept and even appreciate some uncertainty so long as its boundaries are made explicit.

The scientific community's success in promoting more widespread acceptance of the climate crisis and its likely impacts thus hinges on finding ways to convey the inherent uncertainty in such important questions as how soon we are likely to experience a sustained temperature of 1.5°C above preindustrial levels, how much the sea level is to rise in a given location by a given date, or what housing insurance might cost in 2030. Although more research into how to communicate such uncertainty effectively is definitely called for, these results do provide some basis for thinking that it is possible to express uncertainty in the climate domain without a serious loss of confidence in the science behind it.

Effectively Communicating Information Visually

Decades of psychological research has shown that visual representations can have a large influence on one's comprehension and thinking process, an insight that Jordan Harold and colleagues have shown also applies to climate and impact data.[29] As they argue in a 2016 article, scientific graphics such as those provided by the IPCC should be designed to be accessible for multiple stakeholders, including the lay public as well as other scientists and policy-makers.[30] In addition to pointing out ways in which such graphics have too often been sorely lacking, the authors have offered several concrete ways in which climate science communicators can adopt good principles of graphic design arising from insights in the research on visual attention, memory, and learning.

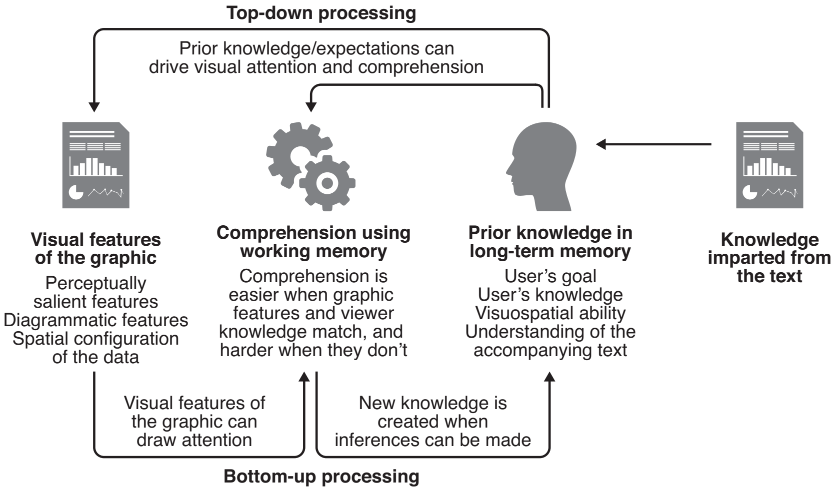
As illustrated in Figure 6.7, visual attention, or the process by which the mind selects or focuses on a subset of the information that is presented, is affected both by what Harold et al. refer to as bottom-up sources, such as color, shape, and size, which can stand out from other features, and by top-down processes of the viewer's expectation, which are driven by prior knowledge (their goal and reason for looking at the graphic and their earlier experiences). When a viewer looks at an image, both the bottom-up and top-down forms of visual attention operate to create a mental representation of the information that is stored in the viewer's memory and updated as the viewer further explores the graphic. According to the authors, the key to good comprehension is matching the perceived information to the viewer's expectations, which can be achieved by creating visual features in a graphic that match the likely prior knowledge of the audience and doing so as simply and clearly as possible.

Figure 6.8 provides an example of how several of the specific principles of good graphic design recommended by the authors can be used to improve the effectiveness of scientific graphics. Among these are reducing potentially distracting clutter by including only the visual information required to comprehend the intended information, using contrast or color to make important elements perceptually salient, putting text close to the graphic information it describes, and using arrows or text to guide viewers to important features of

Figure 6.7

How visual attention, memory, and learning work together

As both top-down and bottom-up visual attention processes do their work, a mental representation of the information is created in memory. The mental representation is updated cyclically as the viewer further explores the graphic.



Adapted from Harold, J., Lorenzoni, I., Shipley, T. et al. Cognitive and psychological science insights to improve climate change data visualization. Nature Clim Change 6, 1080–1089 (2016). https://doi.org/10.1038/nclimate3162

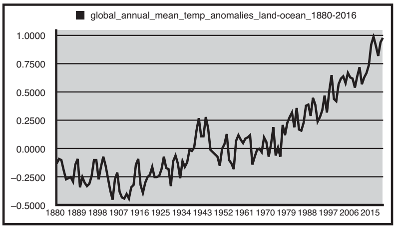
the visual. Other principles mentioned in their article are breaking up the graphic into visual "chunks" that can be sequenced, choosing common graphic elements that viewers will be familiar with, and matching the visual data to metaphors (such as up and down) that aid comprehension.

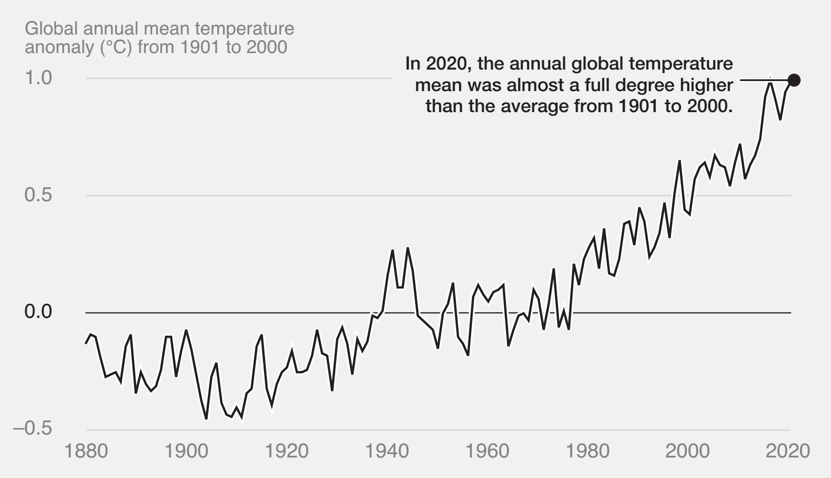
Simulations are another form of data visualization that have been found to be very effective in aiding the public's comprehension of specific climate, impact, and energy information. An excellent example of this communication mode is the En-ROADS simulator developed by scientists and educators at MIT, which shows how much temperature will rise by 2100 on our current emissions trajectory and provides a set of dials that a user can turn to change that trajectory. As shown in Figure 6.9, a user can turn dials that will change the level of renewables, amount of economic growth, and amount of coal that will still be burned and immediately be able to visualize their impact on global heating via an underlying climate model. A research study that used this simulator to engage college students in competitive role-playing showed that the simulator improved students' knowledge of the many aspects underlying

Figure 6.8

Using graphic principles, science communicators can direct visual attention to improve comprehension

The original graphic output (right) is difficult to read and comprehend. Visual clutter like extraneous borders and backgrounds, extra decimal places, and default cryptic labels, as well as a lack of general contrast, obscure the data and make the viewer wonder where to look first. Perhaps more importantly, the overall lack of context forces the reader to search for meaning (what is the point of this graphic? What is it trying to tell me?).





The improved graphic (above) uses graphic principles to focus attention to the salient information:

1. Only required information is presented to reduce clutter. Extraneous borders are gone, while axes have been simplified with fewer breaks and more intuitive intervals.

2. Important elements are highly perceptually salient to capture visual attention. Here, the data, zero anomaly reference point, and contextual explanatory text are darker to attract attention.

3. Graphic elements and text are close so the viewer's attention is not split. The y-axis text is directly above the axis, and explanatory text is close to the data it describes.

4. Arrows or text guide the viewer to important features. Here, explanatory text is linked to the relevant data point with a marker.

For more complex graphics, designers should also make sure that any graphic elements or symbols used are familiar to the intended audience, that data and visual metaphors "match" (e.g. "hot" is red/ "cool" is blue), and that the graphic is broken up into visual chunks that can be sequenced to lead the reader through the information.

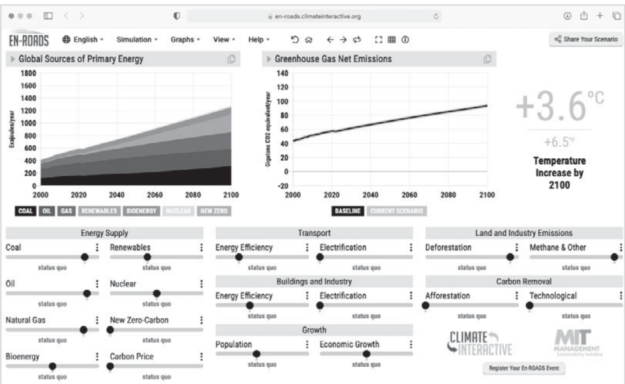
Graphic principles from Harold, J., Lorenzoni, I., Shipley, T. et al. Cognitive and psychological science insights to improve climate change data visualization. Nature Clim Change 6, 1080–1089 (2016). https://doi.org/10.1038/nclimate3162. Data from NOAA National Centers for Environmental Information Global Surface Temperature Anomalies, available online at https://www.ncdc.noaa.gov/monitoring-references/faq/anomalies.php#anomalies

Figure 6.9

An internet simulator allows users to instantaneously evaluate the impact of changing sources of energy and other factors on the global heating trajectory

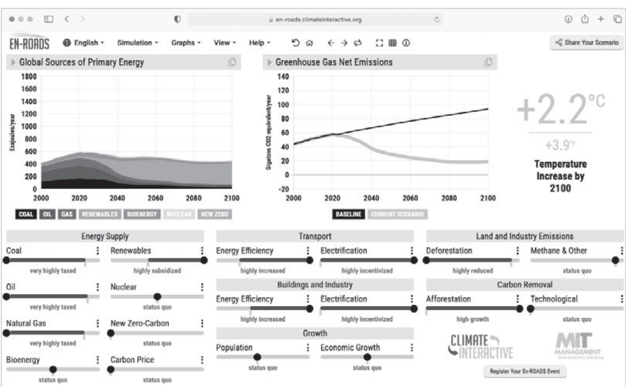
The En-ROADS simulator (www.climateinteractive.org) incorporates a climate model, as well as many assumptions about the dynamics of energy sources, economic growth, afforestation, and other variables.

(A) En-ROADS simulator default mode



WIth the En-ROADS simulator controls in the default mode (roughly our current situation), global heating is predicted to rise approximately 3.6 °C by 2100.

(B) Adjusting the En-ROADS simulator



The simulator shows how specific changes lead to a dramatically reduced heating trajectory: here, all fossil fuels have been heavily taxed/banned, renewables have been maximized, efficiencies increased, deforestation decreased, and afforestation (new trees) increased. These changes limit the predicted heating to only 2.2°C by 2100.

Screenshots from https://en-roads.climateinteractive.org/.

global temperature and increased their personal and emotional engagement with the topic of climate change.[31]

Another example of an effective simulator is a map of sea-level rise, which was shown to increase people's acceptance that climate change is already

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happening.[32] In another study in which people were given a textual description of sea-level rise and then some counter-information that expressed doubt about the source of that text, the presence of an animated map was found to help protect against the doubt.[33] Such simulations are likely to be particularly effective if they relate to one's personal location and could help make estimated effects of global heating such as wildfire damage or flooding much more vivid, one example being a virtual reality simulator of projected sea-level rise in Long Beach, California.[34] Already websites such as cal-adapt.org have been created to provide information about projections of future global heating, such as the predicted effect of the high-emissions pathway (SSP5-RCP8.5) on the number of days of extreme heat for any location on a California map. Such approaches could be made even richer and more consequential by providing more vivid visual displays and building in such information as predicted insurance costs, air pollution, and fire risk.

The visual arts are yet another way in which climate change information can be effectively conveyed. As the authors of one article on this topic have pointed out, the absence of verbal information in visual art can be an advantage in capturing and engaging people's attention, as it forces viewers to relate to climate change personally and create their own interpretations to make sense of the presented visual information.[35] One striking example is the sculpture *Unbearable* by artist Jens Galschiot, shown in Figure 6.10. This large outdoor

Figure 6.10

The sculpture *Unbearable* by Jens Galschiøt, 2015

The artwork shows the connection between the burning of fossil fuels (an oil pipeline), rising global temperatures, and species extinction.

The display of the polar bear resembles a public execution.

Unbearable by Jens Galschiot - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=47680639

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sculpture includes the figure of a bear impaled on an oil pipeline in the shape of the famous hockey stick temperature graph that, starting at 1700 and ending in the present, curves upward as a result of our use of fossil fuels. The work thus provides a powerful image of climate change, including its main cause, resulting rise in temperatures, and a major effect, the extinction of species. A research study on the impact of such artworks on climate beliefs presented at a UN climate summit showed that exposing hundreds of people to climate artworks increased their support for climate policy.[36]

Conclusion

Although people's views regarding climate change are substantially influenced by a range of factors that were discussed in Chapter 5, such as intuitive thinking and memory failures, elite sources cues, emotional state, and motivated cognition (reflecting values and worldviews), the fact that even liberals appear to have a knowledge deficit about the facts about global heating strongly suggests that, in addition to the approaches discussed in Chapter 5, effectively communicating the facts of climate science is a necessary strategy to increase belief in global heating and the steps that must be taken to combat it. Even though much of the extant research on this topic is limited to laboratory-based studies, in which participants are presented with specifically tailored information and asked about their beliefs without any observation of their subsequent actions, the results still provide valuable insights into how real-world communication can be done better. This may well include employing more integrated approaches, such as combining knowledge of the greenhouse effect, the facts of Global Heating 1-2-3, and the stock-and-flow problem and providing practice in confronting misinformation as part of a useful education curriculum in schools and colleges, an approach that is increasingly being considered and even deployed in some US states and countries. Furthermore, many other practices of science communication, such as communicating uncertainty as a point estimate and range (also known as bounded uncertainty) and employing graphics, simulations, and visual art, can help science communicators convey relevant scientific knowledge more clearly and powerfully.

Although science communication is not itself a panacea, as sufficiently overcoming skepticism about global heating will also require contending with people's worldviews and values and confronting the vested interests and power structures of the fossil, utility, and agriculture industries and their political allies, science communication is still an essential part of the toolkit that will be needed to shift people out of their epistemic skepticism, and to gain broader public support for meaningful climate change policies. Such science communication is likely to be more effective still if it also finds ways to convey the risk or threat of global heating, the topic of Chapter 7.