

What Do People Know About Global Climate Change?

1. Mental Models

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A set of exploratory studies and mental model interviews was conducted in order to characterize public understanding of climate change. In general, respondents regarded global warming as both bad and highly likely. Many believed that warming has already occurred. They tended to confuse stratospheric ozone depletion with the greenhouse effect and weather with climate. Automobile use, heat and emissions from industrial processes, aerosol spray cans, and pollution in general were frequently perceived as primary causes of global warming. Additionally, the "greenhouse effect" was often interpreted literally as the cause of a hot and steamy climate. The effects attributed to climate change often included increased skin cancer and changed agricultural yields. The mitigation and control strategies proposed by interviewees typically focused on general pollution control, with few specific links to carbon dioxide and energy use. Respondents appeared to be relatively unfamiliar with such regulatory developments as the ban on CFCs for nonessential uses. These beliefs must be considered by those designing risk communications or presenting climate-related policies to the public.

KEY WORDS: Climate change; global warming; mental model; risk communication; decision making.

1. INTRODUCTION

The last decade has been marked by growing public concern and widespread media coverage surrounding the possibility of global warming due to an increased greenhouse effect.^(1,2) To a significant degree, the effectiveness with which society responds to this possibility depends on how well it is understood by individual citizens. As voters, citizens must decide which policies and politicians to support. As consumers, they must decide whether and how to consider environmental effects when making choices such as whether our resources are most efficiently deployed by using paper or polystyrene foam cups.⁽³⁾ Despite the crucial implications of their knowledge and opinions for public policy, little is

known regarding the public's literacy about global climate change.

The United States spends approximately \$1.5 billion annually researching global environmental change, including climate change. For that research to have any practical value, its results must find their way to decision makers, including individual citizens and policy makers. In order to educate the citizenry, we must start by educating ourselves about what they already know and believe and how it differs from what they need to know in order to make effective decisions. We cannot trust technical experts' intuitions about public beliefs.^(4,5) Indeed, many controversies in risk communication arise when experts either underestimate or overestimate the public's knowledge. Consequently, the provision of information should begin with an empirical assessment of what people already know, along with a scientific determination of what missing information is most critical to their decisions.^(6,7)

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Here, we present three studies directed toward this goal. Study 1 comprised seven interviews with well-educated respondents from Carnegie Mellon University. It raised questions about how well such laypeople understand the basic vocabulary of climate change, questions which were examined directly using a questionnaire as reported in Study 2. Finally, in Study 3 we conducted a second set of interviews with 37 members of the general public. The two sets of interviews are mental model interviews.⁽⁸⁻¹⁰⁾ They begin with general and nondirective questions that allow the expression of beliefs unconstrained by the researcher's expectations; increasingly structured prompts follow.

In our study we first asked each interviewee to "tell [the interviewer] all about the issue of climate change," allowing them to say everything that came to mind. We then asked respondents to elaborate on each of the topics which they brought up. For example, if a subject mentioned the "ozone hole" in their response, we prompted them with "can you tell me more about the ozone hole." Finally, respondents were asked questions designed to elicit their knowledge of the basic elements of a risky process, which include exposure,³ effects, risk assessment, and risk management.⁽¹¹⁾ Figure I reproduces the protocol used in Study 3. This protocol is based on the general structure of an expert decision model, which represents the key components of the hazardous processes that underlie the risk from potential global warming. At the top level are the major global climate change mitigation strategies: prevention, geoengineering, and adaptation. The model flows from greenhouse gas production to potential climate impacts and consequent effects on society. Represented are major energy sectors and human activities that contribute to greenhouse gas emissions, and how greenhouse gas emissions interact with other physical processes to affect other human activities and create adverse outcomes. The model is designed to represent possible lay decisions about global climate change in general, not specific decisions such as what kind of disposable cup to use. However, many such specific decisions follow from the general model.

Research by Willett Kempton and other cognitive anthropologists strongly influenced our earlier development of the mental models interview structure.⁽⁸⁾ After the present studies were undertaken, we became aware of Kempton's ethnographic interviews,⁽¹²⁾ and related studies by Löfstedt.⁽¹³⁾ Kempton's procedure has three parts: (1) questions about weather, the environment in

general, and global warming; (2) a presentation by the researcher on global warming; and (3) questions about policy proposals. Kempton found that laypeople confuse or are unfamiliar with key concepts regarding the causes of global warming, evidence for it to date, and potential policies to mitigate it. Kempton concluded that four sets of ideas dominate lay thinking about climate change: stratospheric ozone depletion, tropospheric pollution, photosynthesis, and local weather phenomena.

Like Kempton's, our interview protocol elicits beliefs about climate change as well as related values, but it differs in several respects. Kempton structured his interviews by asking about several weather-related topics at the outset. As already discussed, we first introduced only the high-level issue of global climate change, thereby allowing respondents to give their own structure to the interview. Only after we had exhausted this avenue did we provide people with more guidance. In order to simulate voter reactions that might occur after a period of public debate on the topic, Kempton also informed his respondents about global warming before asking them to respond to specific policies. We asked about policies without providing such a tutorial.⁴ Finally, while Kempton's probes can reveal some surprising beliefs, our standardized open-ended questions provide a more uniform task that is easier to replicate as well as less vulnerable to the criticism that the reported beliefs are a function of how they are elicited.

2. STUDY 1: PILOT INTERVIEWS

Seven staff and graduate students at Carnegie Mellon University were recruited by an electronic bulletin board to participate in a mental models interview.

2.1. Results and Discussion

Although our respondents were highly educated, their interviews demonstrate many misconceptions. The response of one masters student in public policy to the first, open-ended question illustrates some of these.

OK. Let's see. What do I know. *The earth is getting warmer because there are holes in the atmosphere and this is global warming and the greenhouse effect.* Um. I really don't know very much about it, but it does seem to be true. The temperatures do seem to be kind of

³ The term *exposure* includes sources and exposure paths and processes, thus deviating somewhat from standard usage in risk assessment.

⁴ We are presently conducting controlled studies of the influence of different kinds of communications about climate change on people's beliefs and attitudes.

warm in the winters. They do seem to be warmer than in the past. . . . [When asked to elaborate:] I think there are like holes in the atmosphere and the sun is more powerful because of that. What do I think of? I think of what causes it, I think of Right Guard actually (chuckle), and like, *sprays and things like that, that put holes in the ozone layer.* [Italics added.]

This respondent's comments are quite typical, in that she makes no distinction between the greenhouse effect and stratospheric ozone depletion, explains local weather effects and global warming as direct effects of holes in the ozone layer, and attributes the latter to sprays such as Right Guard, which we interpret as aerosol sprays.

A second example illustrates how some respondents, in addition to equating the greenhouse effect with stratospheric ozone depletion, described the trapping of gases in the atmosphere.

Well, lately I've been hearing a lot on the news about global warming and that's the first thing that came to my mind when I thought about climate change and the only thing I know about it is there's been a big debate as to whether *all the carbon dioxide, the hole in the ozone layer is leading to changes in the world's climate.* [Interviewer: OK. Can you explain. . . . You mentioned here carbon dioxide. Can you explain how that will lead to global warming?] Well, I, this is what I know, my knowledge is really fuzzy on this. Well they, the term that's used is the *greenhouse effect where, um, the sun's rays are allowed into the earth's atmosphere but that the carbon dioxide, I guess, is not allowed to go out and that somehow leads to an increase in the earth's temperature.* [Italics added.]

While this respondent does initially mention carbon dioxide (and not CFCs) in the context of the greenhouse effect, ozone depletion remains an integral part of his mental model of climate change. We suspect that the common belief that climate change is related to the ozone layer is partially due to media accounts conflating the two issues.¹⁴ In addition, aerosol spray cans may be indicted because their manufacturers frequently advertise that they contain no CFCs, despite the fact that CFCs were barred in the United States as propellants in aerosol spray cans in 1978.⁵ Indeed, five of the seven interviewed in this study did mention carbon dioxide or carbon monoxide. Nevertheless, all but one of the seven implicated stratospheric ozone depletion as a *primary* cause. Uncertainty about the possible roles of CFCs and ozone depletion in global warming seemed to have crept into even the relatively sophisticated mental models

⁵ In 1978, CFCs were prohibited as propellants for nonessential use in Federal Register, Vol. 43, No. 53, March 17 1978, pp. 11301-11326, and Federal Register notices FR9205, February 15, 1977, and FR24536-24550, May 13, 1977.

these respondents depicted when they were asked what might be causing global climate change. As one respondent, a former policy analyst who had completed graduate studies and was very knowledgeable about climate change, put it when discussing the causes of climate change:

I can't remember what ozone supposedly has to do with this and whether that's a function of carbon dioxide, but there's ozone in there somewhere. . . . [Interviewer: Can you say anything more?] It seems to me that fluorocarbons and stuff like that contribute some of the same kinds of things to [the] atmosphere or things that have the [same] effect on the atmosphere as does carbon dioxide. Who knows? Maybe its only fluorocarbons and carbon dioxide has nothing to do with it but there's a carbon in there somewhere that's supposedly causing the problem.

Even if media reports were accurate, people might still find CFCs confusing because they play a role in both global warming *and* ozone depletion. CFCs are a potent greenhouse gas and thus a direct contributor to global warming; they also contain chlorine, which acts as a catalyst in promoting the breakdown of stratospheric ozone. Ozone protects the earth from ultraviolet radiation but also has radiative properties (retains heat). Indeed, according to some estimates, as much as 80% of the warming effect of CFCs may be offset by the cooling effects of ozone loss.¹⁵ In any case, CFCs and ozone depletion are secondary in importance to CO₂ as a contributor to global warming.

Our respondents' mental models included few of these subtleties. No one mentioned the radiative properties of CFCs; most suggested that the hole in the ozone layer lets in more ultraviolet light, which heats up the atmosphere. Thus, our results are consistent with Kempton's claim that "the ozone hole has arrived as a concept in the U.S. public's consciousness, but the greenhouse effect is entering primarily as a subset of the ozone hole phenomenon, the closest model available."¹²

Respondents showed varying degrees of sophistication regarding climate change effects, mentioning sea level rise, agricultural and ecosystem impacts, changes in living standards and economic conditions, and an increase in floods and droughts. A few stated that developing countries or poor people would be hardest hit, and some noted the existence of scientific controversy over the level of change. Respondents' estimates of global temperature increases (if current trends continue) ranged from plus or minus a few degrees to an increase of 10°F over the next 30 to 50 years.

These highly educated respondents also suggested a wide range of policy options including education, pol-

lution taxes and control, recycling, forest protections, taxes on polluters, emission-trading schemes, investing in mass transit rather than highways, and investing more in research to increase energy efficiency, as well as adaptation and geoengineering. Many of the options suggested were framed in terms of reduction of CFC emissions. For example, education was proposed:

... People can be educated so that they really see what happens. Like they spray an aerosol can and this is actually what really happens.

Similarly, one respondent defined "polluter" in the following way:

What do I mean by polluters? I guess especially companies of corporations that put out hydro-, what is it HFC or HCFs? Hydro whatever—hydrofluorocarbons, which are especially bad for the ozone. I guess that goes into the making of styrofoam, things like that.

Our preliminary results indicate that even very well-educated laypeople conceptualize climate change issues very differently than do technical specialists. Their mental models of climate change focus more on CFCs than on carbon dioxide or energy use, and sometimes omit the latter. Moreover, they include fundamental inconsistencies based on confusion of the greenhouse effect with ozone depletion, as well as other basic terms.

3. STUDY 2: DEFINITIONS OF GLOBAL CLIMATE CHANGE

To explore which terms related to climate change people are likely to substitute or use interchangeably, we asked laypeople to supply their own definitions of six key concepts: *climate*, *climate change*, *the greenhouse effect*, *weather*, *air pollution problems*, and *ozone problems*.

3.1. Method

Respondents completed this task after they had completed several other unrelated tasks on risk perceptions. Twenty teenagers (average age, 16) and 31 adults (the teenagers' parents; average age, 44) from the Pittsburgh area participated. Two did not complete this questionnaire.

Each respondent received a single sheet of paper on the top of which the following was typed: "Please describe in a few words what (*word to be defined*) means to you," followed by a few blank lines. One of the six

concepts was inserted in the blank. Thus, each term was defined by approximately six individuals.

3.2. Data Analysis

Respondents' definitions were separated from the question that they answered. Six members of the global climate change research group in the Department of Engineering and Public Policy at Carnegie Mellon University received these definitions in random order. Each judge was also given expert definitions of these terms. The judges then matched each lay definition with the expert definition that it fit best.

Table I reports the percentage of judges who assigned each lay definition to the term that the respondent attempted to define. Thus, respondents most frequently produced appropriate definitions for "air pollution problems," and least frequently for "climate" and "climate change," both of which were most frequently miscategorized as being definitions of "weather." Judges often mistook definitions of the "greenhouse effect" for "ozone problems" or "air pollution," while definitions of "ozone problems" were often classified as "greenhouse effect" or "air pollution problems." Clearly, there were gaps between the definitions of experts and those of laypeople.

Several examples of lay definitions of "greenhouse effect" illustrate why the match rates were so low.

The ultraviolet rays are being trapped in the ozone and is effecting the pollution of the earth. (Teen A: 2 judges coded as *greenhouse effect*, 4 as *ozone problems*)

Putting a cap on our atmosphere so that harmful gases cannot escape, our ozone deteriorates, global warming occurs, and our health and environment suffer. (Teen B: 4 judges coded as *greenhouse effect*, 1 as *ozone problems*, 1 as *climate change*)

The effective warming of the "earth" through the trapping in of CO₂ and the addition of pollutants from industry (steel power, etc.). (Adult B: 5 judges coded as *greenhouse effect*, 1 as *air pollution*)

Atmosphere destruction. (Adult C: 1 judge coded as *air pollution*, 5 as *ozone problems*)

Not enough green foliage to remove the carbon dioxide from the atmosphere. (Adult D: 4 judges coded as *greenhouse effect*, 1 as *climate change*, 1 missing)

The confusion between the greenhouse effect and ozone problems is consistent with that found in Study 1, as is the lack of distinction between climate and weather. The response from Adult D illustrates Kempton's "photosynthesis" model, whereby insufficient photosynthesis is believed to cause climate change.¹² Even though tro-

ospheric ozone was not mentioned specifically, the question formulations do not allow one to rule out the possibility that respondents understood correctly how tropospheric ozone might contribute to global warming. However, given their lack of specificity, this interpretation seems unwarranted. These data appear instead to provide evidence of the "air pollution" model (global warming is caused by air pollution in general) that Kempton found in some of his interviews. Table I provides the basis for a more quantitative assessment of the risks of being misunderstood when using terms related to climate change, in terms of both the probability of being misunderstood and the nature of the misunderstanding.

4. STUDY 3: MENTAL MODEL INTERVIEWS

4.1. Subjects

For the third study, participants were solicited during the annual Pittsburgh automobile show. Forty-two participants were interviewed at the show (28 men, 14 women). Due to the noise level and other recording problems, only 37 of these interviews yielded usable transcripts.

About a third of the participants described themselves as having some technical training, and the majority (24, or 65%) considered themselves technically minded. Most (25, or 68%) reported reading the newspaper every day. The highest level of education was reported as some high school by 2 respondents (5%), high school graduate by 9 (24%), some college by 12 (32%), completed college by 8 (22%), and some or completion of graduate studies by 5 (14%). Thus, they are better educated than Pennsylvania residents, of whom 75% are high school graduates, and less than 18% college graduates.⁶ About half (18, or 49%) were between 20 and 40 years of age, eight (22%) between 40 and 60, and four (11%) over 60.

4.2. Procedure

We posted a sign on a booth at the automobile show to notify potential participants that they could earn

\$10 for their participation in an interview conducted by researchers from Carnegie Mellon University. Potential participants were informed that the interviews usually took less than an hour, and that they needed no special knowledge to participate. The topic was left vague, with mention only of climate and the weather. All but one of the interviews was done by a single interviewer, with the exception carried out by a research assistant who had attended all of the previous interviews and had been instructed by the principal interviewer. After each interview, participants completed a one-page demographic questionnaire, along with a few closed-ended questions about global climate change.

All tapes were first transcribed⁷ and then coded according to the categories from the expert model, with nonexpert concepts added to the coding scheme as they arose.⁸ Coding was an iterative process, which included a second complete coding of the data. A reliability check on a sample of four interviews found two independent coders agreeing between 70 and 80% of the time for exposure and effects concepts, and about 60% for the entire coding. This is reasonably high, given that the large number of possible codes makes agreement by chance very unlikely.

4.3. Design and Materials

Figure 1 reproduces the full protocol used in Study 3. It differed from the protocol used in Study 1 in minor ways and the addition of two final tasks. One asks respondents to list the causes of global warming on separate cards, rank order the cards, and then explain why they have ranked them in that order. The second new task poses policy questions regarding the greenhouse effect and U.S. action on climate change.

4.4. Results

We report the interview results in five sections: definitions, exposure processes, effects processes, judgments, and decisions. The first section reports how respondents defined basic climate change terms, thus providing necessary background for interpreting other responses. We then characterize respondents' beliefs about exposure and effects processes to provide a basis for

⁶ Table 223 in the 1992 U.S. Statistical Abstract (112th edition)⁽¹⁰⁾ allows a more specific comparison of education levels with the U.S. population over age 18 (percentages for this sample in parentheses): have not completed high school 22.5% (5%), high school graduates 36.6% (24%), some college 17.6% (32%), and college graduates and above 23.3% (35%).

⁷ The accuracy of transcriptions was verified by comparing the transcriptions and tapes for several interviews, chosen at random.

⁸ The expert model used here was based on the information contained in the IPCC report⁽¹⁰⁾ and was reviewed by other global climate change researchers. It is available on request.

Table I. Average Percentage of Policy Researchers Who Matched Lay Definitions with Expert Definitions Correctly—Task for Lay Respondents: "Please Describe in a Few Words What (*Word to Be Defined*) Means to You" ($N=49$)

Definition requested	Expert definition	Average % correct match of lay and expert definitions	Lay definition most often incorrectly matched with
Air pollution problems	Precipitate, corrosion, or effects on human health due to air made physically impure, unclean, befouled, dirty, or tainted	93	Greenhouse effect
Weather	The state of the atmosphere at a definite time and place with respect to heat or cold, wetness or dryness, calm or storm, clearness or cloudiness: meteorological condition	74	Climate
Greenhouse effect	An increase in the equilibrium temperature of the atmosphere caused by the addition of gases or aerosols which inhibit the outward flow of infrared radiation	58	Ozone problems, air pollution problems
Ozone problems	(1a) Elevated concentrations of tropospheric ozone caused by the photochemical reaction of oxides of nitrogen and reactive organic compounds released by industrial society; (1b) human health effects resulting from this elevated concentration; (2a) depleted concentrations of stratospheric ozone resulting from long-lived catalysis released to the atmosphere by industrial society; (2b) increase in cataracts and skin cancer due to increased UV radiation reaching the earth's surface because of depressed concentrations of stratospheric ozone	57	Greenhouse effect, air pollution problems
Climate	The average course or condition of the weather at a particular place over a period of many years as exhibited in absolute extremes, means, and frequencies of given departures from these means, of temperature, wind velocity, precipitation, and other weather elements	45	Weather
Climate change	A persistent change in the values of climate variables such as absolute extremes, means, and variances, of temperature, wind velocity, precipitation, and other weather elements	44	Weather

understanding their judgments and decisions, which follow.

4.4.1. Definitions

As found in Study 2, people tend to see weather and climate as the same thing: "Climate is the, is the weather" (respondent No. 22); "climate is the weather conditions that are on the earth" (No. 13). Even when respondents recognize a difference, they are fairly inarticulate about it (this is true even of respondents with some graduate education): What is climate? "Um. . .the way our atmosphere acts. Um. . .meaning seasonally, rain, sun, . . .the way the earth rotates" (No. 16). What is climate change? "Anything out of the norm. In other words, having warm winters such as we've had. Extended summers. Hot, dry summers" (No. 16).

When asked "What is the greenhouse effect?" few respondents were aware of the radiative properties of greenhouse gases:

The greenhouse effect is the change in the atmosphere which captures more of the sun's heat energy in the atmosphere. And therefore, there's not as much night cooling, not as much winter cooling. Not as much, you know. The whole ability of the atmosphere to heat exchange out is impeded. (No. 15)

More commonly, people simply equated the greenhouse effect with global warming, leaving the mechanism unspecified:

As far as I know it's, in other words, everything becoming dry and the sun taking over and more or less, the climate just becoming hot. Period. (No. 16)

Greenhouse effect, is, part of it. I don't really know what a basic definition is. Um, the greenhouse effect is, when I think of it, I think of it similar to global warming. (No. 22)

Date: _____ Time: _____
 Subject: _____ Interviewer: _____

Climate Change Interview

This interview is part of our research on risk perception and communication at Carnegie Mellon University. We are interested in how you think about these issues. Don't worry about whether your ideas are right or wrong. We are interested in everything you think about this and want you to say everything you think about these issues.

Tell me all about the issue of climate change ...

Neutral prompts:

- Can you tell me more about _____?
- Can you explain how _____?
- Does _____ bring anything else to mind?
- If you were going to explain climate change to someone else, is there anything you would say differently or add to what you have said?

Now I am going to ask you several questions. Some of these may seem to repeat things you have already said. Please bear with me. I have to ask all of the questions to make sure I have covered everything. You may refer to your previous answers if you feel you have already answered a question and have nothing more to say about it.

Exposure

- What factors might be changing our climate?
- What sorts of climate change might there be?
- How fast will climate change take place?

Effects

- What effects will climate change have?
 - Will climate change affect other things?
- Will the effects of climate change be the same everywhere?
- Will climate change affect everyone/everything similarly?

Benefits/costs

- What might be bad about climate change?
- What might be good about climate change?

Risk Management

- What can be done about climate change?
- Who should be responsible for dealing with climate change?

Scientific uncertainty

- What do scientists think about whether there will be global climate change?
- Is there any chance that climate change won't happen?

Now I am going to ask you for several definitions. These too may seem repetitive. Please bear with me. I'm going to ask for definitions of climate, climate, global warming, the greenhouse effect, weather, ozone, and air pollution. Don't worry about how much you know. We're interested in what you think about these things. Ok, now I'm going to ask you for the definitions, one at a time.

Climate change

- What is "climate?"
- What is "climate change?"
- What is "global warming?"
- What is the "greenhouse effect?"

Fig. 1. Protocol used in the mental-model interviews on global warming.

In many cases, definitions of the greenhouse effect involved vague references to the ozone layer. Many respondents gave a literal interpretation of "greenhouse," perhaps inferred from the question. As these examples show, these errors often occurred together:

I don't understand exactly how the ozone layer and all this stuff works, but I guess it must be very similar to how a greenhouse works. (No. 4)

Uh, I've heard of that. It's when the warm I think it's the warm air, can't get out. We build up an ozone layer. I've heard of it and yet my mind has gone blank. But I think it's the greenhouse. . . like if you raise orchids in a greenhouse, the moist heat stays there. (No. 14)

That's like, um, I must be wrong on some of these things, I thought I just kind of described it. There is this ozone layer, and we're creating a greenhouse where things are getting too warm and not enough of um, oh. . . but it takes from the . . . the products that come from the trees and I'm not. . . has something to do with the chlorophyll. I'm not sure. (No. 11) [This also illustrates the photosynthesis model.]

My understanding of that is that it's a warming effect. But I don't completely understand. Because, to me, in a greenhouse it's also warm and it's also moist. So I don't know where that's coming from, but that's how I think about it. (No. 13)

While these responses are inconsistent, it is evident that subjects recognize that their knowledge is incomplete.

4.4.2. Exposure

Table II lists the causes of global warming mentioned by 10% or more of our subjects during the open-ended interview. As can be seen, stratospheric ozone depletion was cited by almost everybody. In fact, 73% brought it up in response to the general prompt with which the interview began. When asked to elaborate, respondents typically described the process noted in Study 1—that holes in the ozone cause global warming by letting more heat into the earth's atmosphere. Consistent with this (as people seem to equate solar energy with both UV and heat), 70% mentioned UV explicitly sometime in the interview. Also consistent with this "ozone confusion," many mentioned aerosol cans, with fully 22% implicating hair spray in particular. Tropospheric ozone was never mentioned, despite the ample opportunities the interview provides for this.

The only candidate greenhouse gases mentioned by name were ozone, carbon dioxide, and carbon monoxide. Most notably, not one subject cited methane as a

Weather

- What is "weather?"
 What is "weather change?"

Ozone

- What is ozone?
 What ozone problems are there?
 What effects does ozone have?

Pollution

- What is air pollution?

Can you tell me if (and if so how) air pollution has anything to do with

- climate change
 global warming
 the greenhouse effect
 weather change
 ozone

Please list all of the causes of global warming that you can think of (*write on cards*):

Do you believe that there is or will be a greenhouse effect?

Do you believe that all of the factors you mentioned will contribute to that greenhouse effect?
 (If not, which will - *hand subject cards*)

Now, please order these factors by importance (First=most important, Second=next most important, etc.) and explain why you are ordering them this way. So, to start with, please tell me why _____ is the most important cause of the greenhouse effect.

Do you think a greenhouse effect would be good, bad, or neutral? Why?

Do you think a greenhouse effect would be good, bad, or neutral for you personally? Why?

Do you think that the United States should do anything about this? (If yes) What?

Who or what did you think I meant by "the United States?"

How was it to participate in this interview?

Were any questions too hard, unclear, or unpleasant to answer?

Were there any issues related to climate, weather, or the greenhouse effect that you thought of but didn't get a chance to talk about? (If so) What issues?

October 26, 1990

Fig. 1. Continued

cause. More generic descriptions that might describe these gases, such as pollution and industrial emissions, were widely cited. While links between pollution and radiatively active gases sometimes appeared, they were not the norm. Fossil fuel use, which is the primary source of anthropogenic carbon dioxide, was cited by a significant minority—although certainly with much less frequency than the more generic terms.

Apart from aerosol cans, the most frequently cited specific cause of global warming was the automobile. We considered that the frequent implication of automobile use, automobile exhaust, or pollution from automobiles may have been encouraged by the interview venue (an auto show). However, similar results were found in surveys conducted in very different settings.⁽¹⁴⁾ We can conclude, therefore, that people apparently do believe the automobile to be a major contributor to warming. Deforestation was also widely cited. However, when subjects elaborated, they focussed on the loss of the air-cleaning capacity of forests, rather than their role in carbon dioxide sequestration. Even space exploration was raised as a cause. Respondents apparently believed that large spacecraft punch holes in the ozone layer.^(9,19) One respondent suggested that

NASA consider sending its launches through a single hole, so as to avoid making new ones. A few respondents mentioned that nuclear power could contribute to global warming. Only one subject explicitly mentioned the production of electricity as a cause of global warming.

The card-sorting task simplifies the above picture. Most respondents (75%) included three or fewer causes (avg, 3; SD, 1.25). Table III lists those causes mentioned by more than one respondent, from most to least frequently mentioned. Overall, respondents did fairly well in targeting significant sources of greenhouse gas emissions. Although subjects were pressed to be as specific as possible, they chose causes at very different levels of specificity (e.g., aerosol cans versus overpopulation). Some topics included here indicate that respondents might seem more knowledgeable on closed-ended questions—such as the mention of rotting landfills, which could refer to methane. However, even combining categories such as fossil fuels and hydrocarbons does not change the general picture. Automobile emissions, deforestation, industrial air pollution, and the stratospheric ozone depletion model described previously dominated these importance judgments (see Table III).

Table II. Potential Causes of Global Warming Mentioned During Open-Ended Interview in Study 3 (*N*=37)

Cause of global warming	% of respondents mentioned
Stratospheric ozone depletion	95
Pollution and air pollution	86
Aerosol cans	70
Automobile use, exhaust, or pollution	70
Industrial emissions	68
Deforestation	43
Acid rain	30
Chemicals	30
Fossil fuels	30
Energy use in buildings	24
Carbon monoxide	22
Carbon dioxide	19
Space exploration	16
Nuclear power	11

4.4.3. Effects

Respondents identified a wide range of possible effects of climate change, many of which agree with the expert model. Table IV depicts the effects of global climate change mentioned by 10% or more of our subjects. As can be seen, respondents did not hesitate to mention second- and third-order effects, long-term effects, and even some feedbacks—some subjects who cited the changed demand on heating and cooling observed that this could further aggravate global warming. It appears that the risk of global climate change readily excites the imagination. Whether they were inferred or remembered, the variety of UV-related human health effects (e.g., skin cancer and sunburn) illustrates the pervasive influence of basic misconceptions, such as ozone confusion, and their potential to influence judgments and decision making.

One possible short-term consequence of global climate change, frequently discussed in the literature and popular press, is an increase in coastal damage due to increased tropical storm strength and frequency. No one alluded to this possibility. Of course, our study was conducted before Hurricane Andrew, and it is possible that this hurricane has drawn public attention to this threat in much the same way that the hot summers of the 80s made global warming so salient a possibility.

4.4.4. Judgments

When respondents were asked about the existence of a greenhouse effect (bear in mind that their definitions

Table III. Card-Sorting Task Results in Response to "Please List All of the Causes of Global Warming that You Can Think of": Ranking Is for Importance of Contribution to the Greenhouse Effect in Study 3 (*N*=37)

Cause of global warming*	% of respondents		
	Mentioned	Ranked first	Ranked second
Auto emissions	35	10	18
Deforestation	33	15	10
Factory pollutants	30	8	15
Air pollution	25	13	10
Aerosol cans	25	5	3
Stratospheric ozone depletion	23	8	3
Chemicals	5	8	3
Fossil fuels	10	3	3
Jet emissions	8	—	3
Overpopulation	8	5	3
Chlorofluorocarbons	8	3	5
Burning waste	5	3	3
Excessive combustion of energy	5	3	3
Toxic waste pollutants	5	3	3
Hydrocarbons	5	3	—
Climate change	5	3	—
Missiles/space exploration	5	—	3
Nuclear power plants (heat)	5	—	—
Greenhouse effect	5	—	—

* Only causes written on cards by two or more respondents are included. Those written only once include nonuse of safer energy, wood-burning stoves, not enough biodegradable products, landfills rotting, decreasing levels of CO₂, acid rain, nuclear testing, nuclear power plants (heat), damming of water, environmental changes by people, the earth's axis, changing solar system, nature, and life, living, and the pursuit of happiness.

of this term varied), 53% agreed that it does or will exist, 16% said that there was no greenhouse effect, and 16% said that they did not know. When asked whether the greenhouse effect is good, bad, or neutral, most of our respondents judged that the greenhouse effect is bad in general (75%) and for them personally (51%). Asked what might be good about the greenhouse effect, 27% said that there were no positive effects, 14% mentioned less snow, and 14% mentioned warmer temperatures. Specific bad effects mentioned in response to this question included effects on agriculture (30%), lifestyle changes (27%), and effects on the ecosystem (22%).

Most subjects (78%) felt that scientists agree that there will be global climate change. Only 11% personally thought that climate change would not happen, while 8% said that global warming has already taken place, and nearly half (46%) thought that it will happen. Several spontaneously suggested that it can be reduced or stopped. This is consistent with written responses to

Table IV. Effects of Global Warming Mentioned During Open-Ended Interview in Study 3 ($N=37$)

Effect of global warming	% of respondents mentioning
Increases in temperature	89
Changes in precipitation patterns	86
Human health effects (e.g., skin cancer, sunburn, psychological changes)	83
Ecosystem impacts	81
Changed agricultural yields	59
Melting of polar ice caps	54
Chronic flooding	46
Financial and economic changes	41
Reduced photosynthesis	35
Changes in seasons (e.g., longer summers, short winter)	32
Sea level rise	30
Changes in local weather	30
Changing demand on heating and cooling	22

the questions at the end of the interview; no one agreed that change in climate due to human actions was impossible, while most (57%) felt that it was very likely, and many (24%) indicated that it was certain. When asked what size of temperature change they were thinking of for this question, the median response was 10°F average warming, with 38% of the responses falling in the 0–5°F range. Estimates of temperature change correlated negatively with respondents' highest level of education [$r(35) = -0.42, p=0.014$].

4.4.5. Decisions

Suggested mitigation strategies included everything from social or political activism (57%; e.g., joining Greenpeace) to creating a synthetic ozone layer (mentioned once). Other mitigation strategies mentioned frequently include air pollution controls (51%), environmental measures other than energy conservation such as recycling (41%), banning aerosol products (38%), energy conservation or efficiency (32%), use of alternative fuels (30%), letting scientists take care of it by relying on new technology or doing more research (30%), educating the public (27%), and government regulation (e.g., regulation of industrial emissions, 24%; of automobile emissions or efficiency, 22%).

Asked if the United States should do anything about global climate change, 87% of respondents said yes. The most popular specific courses of action were regulating emissions or pollution (35%) and interna-

tional cooperation and leadership (27%). There were, however, multiple perceptions of exactly who or what "the United States" meant in this case, including the people of the United States (29%), the U.S. EPA (14%), and the government (federal or unspecified) (27%).

Of the 8 respondents (22% of the total) who mentioned alternative energy sources as a possible mitigation measure, 5 had previously cited fossil fuels as a cause of global climate change (of 11 total who mentioned fossil fuels as a cause). All but 2 of the 14 respondents who suggested banning aerosol cans or CFCs in aerosol products were among the 26 (70%) who had previously stated that aerosol products contribute to global warming. Thus, interviewees with misconceptions about exposure were more likely than others to mention mitigation measures that correspond to those misconceptions, although many revealed inconsistencies in their beliefs.

5. DISCUSSION

Our results suggest that, despite widespread media coverage of global climate change and related issues, lay mental models of global climate change suffer from several basic misconceptions. First, explanations of the physical mechanisms underlying global climate change were inconsistent and incomplete. Virtually everyone who provided a mechanistic account made the error that climate change is caused by increased ultraviolet light entering the atmosphere due to stratospheric ozone depletion caused by CFCs. Second, many held other fundamental misconceptions, such as the literal interpretation of the greenhouse effect as involving increased steaminess on earth or that there is a cap on the atmosphere that prevents noxious gases from escaping. Third, more subtle misperceptions about the relative importance of various causes of global warming were common. We refer to the latter as peripheral beliefs, because they constitute undue focus on processes that are correct but relatively insignificant. For global climate change, peripheral beliefs are hard to separate from more fundamental errors but still appear to influence attitudes. The exaggerated importance given to deforestation as a cause of climate change exemplifies one of these elevated peripheral beliefs.

In many cases, these misconceptions coexisted with correct beliefs. Most notably, many respondents who considered ozone depletion to be essentially synonymous with global climate change also believed that automobile emissions were an important contributor to that

change. However, our findings suggest that this belief may be a relatively isolated "fact" (possibly resulting from media accounts), neither caused nor supported by an appropriate mechanistic view of the role of carbon dioxide. In support of this view, few people mentioned any greenhouse gases apart from CFCs, and those who maintained that deforestation could change climate held this to be caused by the loss of the plant's ability to clean air, rather than by the destruction of carbon sinks. Some respondents did make the connection between energy use and possible global warming. However, that was relatively rare even in this overeducated sample.

Although respondents believed that climate change is a threat and favored action to address it, their flawed mental models restricted their ability to distinguish between effective and ineffective strategies. One particular concern is that laypeople may waste their energies on ineffective actions, such as conscientiously refusing to use spray cans, while neglecting such critical strategies as energy conservation. Respondents' beliefs, even when correct, may lack the specificity necessary to support such decision making (e.g., air pollution causes global warming).

While the nature of the samples studied here limits their generalizability, by allowing respondents to structure and define their own responses, we can offer a clearer perspective on how people conceptualize and describe these issues than is possible with a conventional national survey, with a uniform wording of potentially unfamiliar questions and responses. To illustrate, a national survey done by Environmental Opinion Study, Inc.,⁽¹³⁾ asked respondents to rank the seriousness of several environmental problems including air pollution, damage to the earth's atmosphere, destruction of forests, global warming by the greenhouse effect, inefficient energy use, and reliance on natural fuels like coal and oil. One must wonder how respondents interpreted these terms. If they showed the same variability in interpreting the other terms as we found with "climate change" and "greenhouse effect," then the responses to these questions would be an unreliable guide to their beliefs and priorities.

Surveys of large, random samples can justify generalizing results to the public at large but will not usefully inform risk communicators and policy makers if they suffer from these flaws. To avoid these, survey instruments must be based on exploratory work such as that reported here. We have used these studies to design a fixed response survey instrument. The results of one investigation using this instrument are reported in a companion paper.⁽¹⁴⁾

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