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What Do People Know About Global Climate Change? 2. Survey Studies of Educated Laypeople

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Drawing on results from earlier studies that used open-ended interviews, a questionnaire was developed to examine laypeople's knowledge about the possible causes and effects of global warming, as well as the likely efficacy of possible interventions. It was administered to two well-educated opportunity samples of laypeople. Subjects had a poor appreciation of the facts that (1) if significant global warming occurs, it will be primarily the result of an increase in the concentration of carbon dioxide in the earth's atmosphere, and (2) the single most important source of additional carbon dioxide is the combustion of fossil fuels, most notably coal and oil. In addition, their understanding of the climate issue was encumbered with secondary, irrelevant, and incorrect beliefs. Of these, the two most critical are confusion with the problems of stratospheric ozone and difficulty in differentiating between causes and actions specific to climate and more general good environmental practice.

KEY WORDS: Climate change; global warming; risk communication; public understanding.

1. INTRODUCTION

In the preceding paper,[1] we used open-ended interview methods to study how well several convenience samples of well-educated laypeople understand the issues surrounding climate change. We discovered a mixture of correct and incorrect beliefs (e.g., viewing the ozone hole as the principle cause of climate change, not realizing the role of carbon dioxide and fossil fuel consumption). We hypothesized that some of these misunderstandings could misdirect the public's support for proposed policies, as well as leave it vulnerable to manipulation by interest groups.

Open-ended elicitation procedures allow people to express their beliefs naturally, with a minimum of constraints imposed by the investigator's perspective. Unfortunately, they are very labor intensive and, thus, tend to have small samples. We used results from our previous interviews, and from related studies by Kempton,[2] to construct a structured questionnaire which can be administered to large numbers of subjects. In this paper we give a more precise indication of the frequency with which beliefs observed by Bostrom *et al.* and by Kempton are encountered among well-educated laypeople. We reasoned that the beliefs and opinions of such well-educated people are of particular importance because they may be opinion leaders in their communities and are likely to take on activist and leadership roles—indeed, one of our samples comprised a group aspiring to leadership positions in the city of Pittsburgh. Moreover, the beliefs about technical issues held by well-educated people will probably constitute an "upper boundary" of sophistication; if our sample makes an error, it is unlikely that the error will be less common in a less educated sample.

Our work is designed to direct the content of risk communications as well as assess the level of public understanding. Risk communication will be most suc-

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cessful and efficient when it is directed toward correcting those knowledge gaps and misconceptions that are most critical to the decisions people face. This paper provides risk communicators with knowledge about those gaps and misconceptions.

2. METHOD

2.1. Materials

The questionnaire assessed beliefs about the major concepts in an expert model of climate change processes as well as the most frequent of the critical nonexpert concepts identified in the preceding studies.[1,2] These questions addressed four major topics: (1) basic facts about weather and climate processes, including definitions of "global climate change" (19 items); (2) causes of climate change (15 items); (3) effects of both the greenhouse effect and global warming (15 items); and (4) the effectiveness of diverse policy responses (21 items). Items from categories 1–3 were all answered on a 5-point scale comprised of "true," "probably true," "don't know," "probably false," and "false." Those in Category 4 were judged on a 6-point scale consisting of "slow or stop global warming," "slightly slow global warming," "no effect," "slightly speed global warming," "speed global warming," or "don't know." Several additional open-ended questions are described below. A series of demographic questions appeared at the end. The questionnaire was piloted on a small opportunity sample of Carnegie Mellon students and staff.

2.2 Respondents

We distributed the questionnaire to two samples of citizens, 177 in all. The *Point Park* sample consisted of 140 participants in the July 4th celebrations at Pittsburgh's Point State Park. Ages ranged from 17 to 68 (mean, 34; SD, 12.4). Fifty-nine percent were female. Overall, they were well educated: 89% had finished high school, 53% had completed college, and 25% had at least some graduate training. This level of education is much greater than the national average, where only 77.5% have finished high school and 23.3% have finished college.[3] Subjects were recruited with a sign offering $2 for participating in research being conducted by Carnegie Mellon University but saying nothing about the topic. Consequently, while the sign may have attracted people who wanted to know about university research, it is unlikely that it systematically screened people on the basis of their environmental convictions.

The *Leadership Pittsburgh* sample was an opportunity sample of 37 members of a group organized by the city's Chamber of Commerce as a forum for local business and government issues. The members aspire to positions of leadership in business or government and consist largely of small-business owners, local government officials, and middle-level managers. Ages ranged from 33 to 60 (mean, 42; SD, 6.7). Fifty-two percent of the subjects were male. This sample was even more highly educated: All had finished high school, 94% had completed college, and 70% had at least some graduate training.

2.3. Data analysis

Responses to true–false questions (categories 1–3) were characterized in terms of a *degree of agreement* (DA) index, ranging from 2 (complete agreement with the statement) to −2 (complete disagreement). For category 4 answers, a *belief in abatement* (BA) index was created, ranging from 2 (strong belief that a strategy would abate climate change) to −2 (strong belief that strategy will aggravate climate change). Because judgments of "don't know" and "no effect" could imply either that respondents do not expect an effect, that they expect an effect but do not know its direction, or that they do not have enough information to predict an effect confidently, these responses were assigned a value of 0. In those cases where several closed-form questions addressed the same issue (e.g., causes or effects of global warming), we first performed one-way repeated-measures analyses of variance on the data and then calculated Tukey's honestly significant difference (HSD), which is the amount by which a pair of means must differ in order to be considered significantly different.

For the open-ended questions, responses were classified by a trained coder. In order to compute interjudge reliability, a second coder classified the responses from a randomly chosen subset of 15 subjects. Because the probability of chance concurrence was low (always $<.1$), reliability was assessed in the form of percentage agreement between raters. The classifications discussed in the text are those made by the first coder.

Unless otherwise stated, claims regarding what scientists believe are derived from the report of the Intergovernmental Panel on Climate Change (IPCC).[4]

3. RESULTS

3.1. Differences Between Samples

For 59 of the 71 items, the Point Park respondents either provided the highest rating of the effectiveness of abatement options or were most likely to judge true–false items to be true. In 17 cases this difference was statistically significant ($\alpha = .05$), and the overall difference was also significant [for BA, $t(50) = 5.92$, $p<.001$; for DA, $t(20) = 5.78$, $p<.001$]. In no case was the Point Park sample's belief in abatement (BA) or degree of agreement (DA) significantly lower than the Leadership Pittsburgh sample. These intersample differences reflect a tendency for the Point Park subjects to agree with statements posed by the investigators and to give more extreme responses. That is, where the typical Point Park response might yield a BA index of 2 or 1, the corresponding Leadership Pittsburgh response would yield 1 or 0. In a task where most questions elicited responses on the "positive" side, the variability in the responses of the Point Park subjects was much greater than that of the Leadership Pittsburgh group [mean SD = 1.67 vs 1.18; $t(177) = 4.3$, $p<.001$]. Nonetheless, there was a high level of agreement about the relative truth of the true–false items ($r = .94$) and the efficacy of the abatement options ($r = .93$). Given this agreement, we combined the groups for subsequent analyses.

3.2. Has Warming Occurred, and How Much?

We asked subjects, "How likely do you think it is that human actions have changed global climate?" Although scientists disagree about the answer, 37% of subjects thought that such change was certain, while an additional 61% thought that it was at least "somewhat likely."

Figure 1 presents cumulative frequency distributions of our subjects' estimates of the amount of warming that has already occurred and will occur in the next 10 and 50 years, contrasted with distributions we have constructed making plausible assumptions about the consensus judgments published by IPCC.[4] Subjects responded in degrees Fahrenheit, transformed into degrees centigrade for Fig 1. Few scientists believe that warming to date exceeds 0.5°C. Our subjects' median estimate was 1.9°C (mean, 2.7°C). If greenhouse gas emissions remain unchecked, the IPCC predicts (under their "business as usual" scenario) that warming of the order of 0.3°C (range, 0.2 to 0.5°C) will occur per decade. As shown in Fig. 1, our subjects' estimates were far larger.

3.3. Basic Processes

3.3.1. Climate Versus Weather

Bostrom *et al.*[1] report that many of their subjects had difficulty distinguishing between weather and climate. To explore this issue we asked six questions. We began with two statements: "Climate means average weather" and "Weather means average climate." Although mean DA scores were in the correct direction for each question, 32% disagreed with the first correct definition and 23% agreed with the second incorrect definition. The second pair of statements read "Climate often changes from year to year" and "Weather often changes from year to year." Forty-two percent erroneously said the first statement was true or probably true, while only 11% erroneously disagreed with the second statement. Finally, 78% correctly rejected the statement that "the earth's climate has been pretty much the same for millions of years."

While 72% of respondents disagreed (DA = −.93) with the incorrect statement "Climate means pretty much the same thing as weather," 22% agreed. We separated subjects into *believers*, those who stated that it was at least probably true that climate and weather were the same, and *nonbelievers*. We found that significantly more believers agreed that weather was average climate [45 vs 17%; $\chi^2(1) = 12.84$, $p < .001$], that climate changes from year to year [61 vs 37%; $\chi^2(1) = 6.88$, $p < .01$], and that "climate means average weather" [76 vs 58%; $\chi^2(1) = 4.19$, $p < .05$]. Thus, the believers hold an internally consistent set of beliefs about these terms, even though those beliefs are inconsistent with meteorological definitions.

Believers provided significantly fewer correct responses to 2 of the remaining 17 weather statements: (1) "The temperature of the earth is affected by how much dust there is in the atmosphere" [73 vs 86%; $\chi^2(1) = 7.71$, $p < .01$]; (2) "The atmosphere carries heat from the north and south poles to the equator" [30 vs 15%; $\chi^2(1) = 4.29$, $p < .05$]. It appears that belief in the synonymy of weather and climate is a symptom of a general lack of knowledge about weather and climate processes.

Confusing climate and weather can have important consequences. The heat of several summers during the 1980s greatly intensified public fears about global warm-

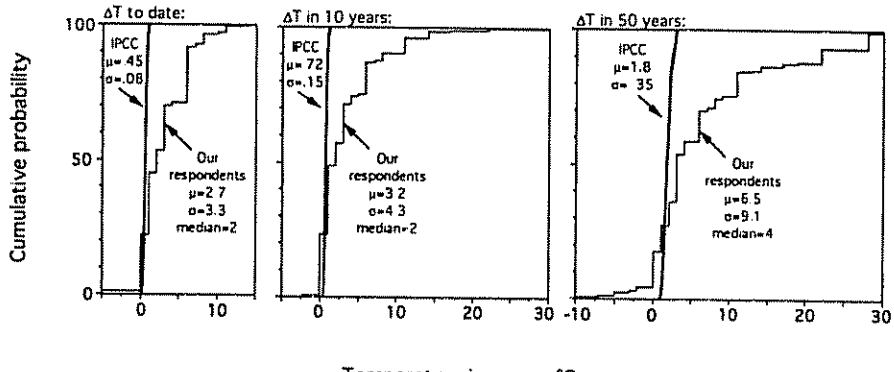

Fig. 1. Cumulative distributions of respondents' point estimates of the amount of warming that has occurred to date (left), will occur in 10 years (center), or will occur in 50 years (right), compared with a distribution that we have derived making plausible assumptions about the IPCC consensus estimates.[4] The latter distributions are based on the assumption that change-to-date is normal ($\mu = .45$, $\sigma = .075$) and that the additional change in 10 years and in 50 years will be the average of IPCC scenarios IS92a, IS92b, and IS92d, whose uncertainties have been taken to be lognormally distributed, with geometric standard deviations of 1.5.

ing. Our data suggest that people were using information about *local weather* to make inferences about *global climate*. There are many precedents for this tendency of people to use single cases to make judgments requiring large bodies of summary data.[5] A failure to recognize that climate is a statistical concept having a low correlation with individual local weather excursions such as "hot spells" may contribute to weather-related fluctuations in public concern about global warming. We recommend that risk communicators explicitly point out this potential confusion, draw a clear distinction between weather and climate, and illustrate the difference with examples whenever possible.

The confusion between the two terms also suggests that one should be *very* cautious in making inferences from national survey results which ask people about beliefs or policy preferences related to "climate" or "climate change."

3.3.2. *Climate Processes*

We asked people about several climate processes crucial to the understanding of discourse about global warming. Our subjects showed a strong degree of agreement with the statement that the earth's temperature is influenced by the sun [96% true or probably true (T or ≈T); DA = 1.70], the ocean (63% T or ≈T, 16% F or ≈F; DA = .92), and the gases in the atmosphere (93% T or ≈T; DA = 1.52) and that the "greenhouse effect" occurs when the atmosphere traps heat from the sun (81% T or ≈T; DA = .98). Nonetheless, they were split over whether the greenhouse effect "keeps the earth from being as cold as outer space" (48% T or ≈T, 39% F or ≈F; DA = .07), suggesting that many people do not view the greenhouse effect as a normal process vital to our survival.[3] They were also ill informed about global scale movement of heat. People weakly agreed with the correct statement that the atmosphere carries heat from the equator to the poles (41% T or ≈T, 30% F or ≈F; DA = 0.13) and only weakly disagreed that heat moves *from* the pole *to* the equator (18% T or ≈T, 48% F or ≈F; DA = 0.56). Less than 25% of our subjects answered both questions correctly.

Cloud cover influences the earth's temperature by increasing its albedo[4] and by inhibiting outgoing infrared radiation. Increasing albedo also causes the reduced temperatures associated with dust suspended in the atmosphere (aerosols) and, consequently, of large volcanic eruptions, whose effect is to increase aerosols. Answers to several questions suggest that people have a moderate understanding of the concept of albedo. Most recognized that clouds (48% T or ≈T; DA = 1.11), dust suspended in the atmosphere (83% T or ≈T; DA = 1.22), and large volcanic eruptions (73% T or ≈T; DA = .98) all influence temperature. Nonetheless, only 57% agreed (T or ≈T, 22% F or ≈F; DA = .66) with the (correct) general statement that "the temperature of the earth is affected by whether the earth's surface is light or dark colored." Answers to one of the abatement-strategy questions (discussed in Section 3.6) suggests that some people may

[3] The statement we used involves a simplification. Without an atmosphere, the earth would be considerably colder, but arguably not the same temperature as "outer space." Respondents with a detailed knowledge of thermodynamics might thus have answered "false."

[4] Albedo is a dimensionless constant that defines planetary reflectivity, ranging from 0 (no reflection) to 1 (perfect reflection).

Table I. Most Frequently Mentioned "Things" that "Could Cause Global Warming": Responses Were Provided to an Open-Ended Question that Asked for a List

Response	% mentioning
Reduction of biomass	57
Automobiles	41
Industry	32
Pollution	30
Depletion of ozone layer	27
Aerosol cans	26
CFC emissions	20
Burning fossil fuels	18
Gases/chemicals	18
Nuclear power/weapons	15
CO_2	14
Natural causes	14
Overpopulation	11

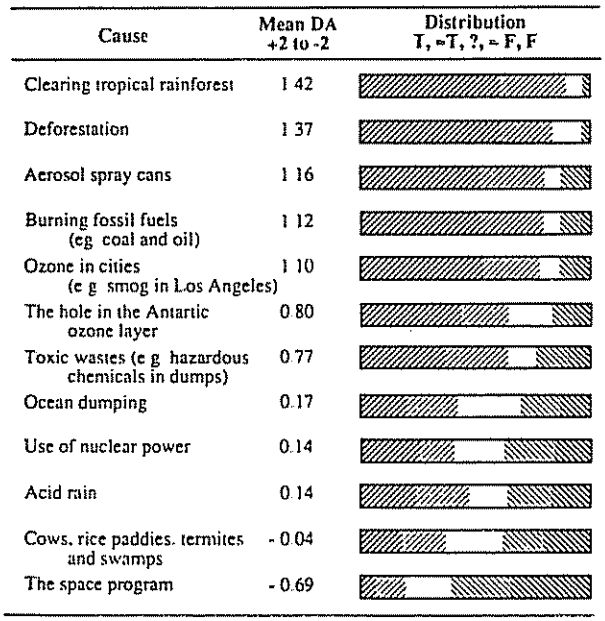

Fig. 2. Responses to closed-form questions about causes of global warming, rank-ordered by mean DA index. The full distribution of responses is displayed in the right-hand column. T means true; ≈T means probably true; ? means don't know; ≈F means probably false; F means false.

believe that dust in the stratosphere *increases* the temperature.[5]

In another albedo-related question, only half endorsed the correct statement that climate can be affected by meteor impacts (36% T or ≈T, 30% F or ≈F; DA = .09), which influence climate by lofting dust into the atmosphere. This is approximately the same number as believe incorrectly that climate can be affected by the phase of the moon (37% T or ≈T, 37% F or ≈F; DA = 0) or earthquakes (32% T or ≈T, 37% F or ≈F; DA = −.04).

[5] There are indeed some circumstances in which dust in the atmosphere can produce a net warming effect, although this is not true for the case described here.

3.4. What Causes Global Warming?

Subjects were asked to "please list all of the things that you think of that could cause global warming," as well as to answer 12 multiple choice-questions about causes. We also asked whether there was anything that they "personally do that contributes to global warming" and, if so, "What things that you do were you thinking about?"

The correct answer would be that the major cause of global warming is anthropogenic emission of greenhouse gases, principally carbon dioxide, but also methane, CFCs and nitrous oxide. The destruction of forests and other vegetation contributes in a more modest way, through emission of greenhouse gases, removal of carbon sinks, and changes in albedo.

For the open-ended question regarding general causes, the 171 subjects gave 688 separate responses, which were classified into 34 separate categories, 1 of which contained 10 miscellaneous entries. The two independent raters agreed on 86% of the classifications. Table I lists the causes of climate change cited by 10% or more of the participants. Figure 2 summarizes the results of the 12 closed-form questions, which are rank ordered by mean DA. A one-way ANOVA on the DAs to the closed-form questions showed a highly significant effect [$F(11,1859)=59.0$, $p<.001$, HSD=.20]. Responses to open and closed questionnaires were in moderate agreement, although some causes that were frequently mentioned in the open-form question were not included in the closed-form alternatives (e.g., automobiles), while some causes widely indicated in the closed-form questions were rarely or never mentioned in the open-form responses (e.g., tropospheric ozone).

As shown in Table I and Fig. 2, loss of biomass, particularly in the forms of tropical rainforest loss and deforestation, is seen as the leading contributor to global warming. Fossil fuel consumption is ranked lower in both lists. Irrelevant issues regarding stratospheric ozone, as well as local and regional problems of general pollution such as toxic materials, were seen as important. Major sources of methane were mentioned by no subjects in the open-ended format, while being ranked as "irrelevant" in the closed format.

Table II. Behaviors Most Frequently Cited as "Things" Which Respondents Do that Contribute to Global Warming: Responses Were Provided to an Open-Ended Question that Asked for a List

Response	% mentioning
Drive	58
Use aerosol cans	38
Use air conditioning	14
Don't conserve	11
Consume environmentally unfriendly products	11
Generate too much waste	10

Although CFCs were mentioned in 17% of the open-form responses, this apparently reflects confusion with stratospheric ozone. Some ozone issues, including ozone layer depletion, CFC emissions, aerosol cans,[6] and the use of styrofoam were mentioned by 41% of respondents to the open-ended question. Subjects strongly agreed about the contribution to global warming of both tropospheric ozone pollution in cities[7] (DA=1.10) and the hole in the Antarctic stratospheric ozone layer (DA=.80).

3.4.1. Responsible Countries

We asked whether three countries were "among the top five nations contributing to global warming:" The United States, currently the largest contributor of greenhouse gases; China, currently third and likely to move up as it grows economically; and Bangladesh, an insignificant source. Our subjects' beliefs were in line with these rankings. The DA was 1.4 for the United States, 55 for China, and −.45 for Bangladesh [$F(2,346)$= 169.8, p=.001, HSD=.34; all pairs of DAs differ significantly].

3.4.2. Personal Responsibility

Subjects stated whether there was anything that they "personally do that might contribute to global warming?" and, if so, "What things that you do were you thinking about?" Of the 75% who answered "yes" to the first question, many apparently misinterpreted it, because 34% offered suggestions typically considered to *reduce* climate change (e.g., "stop using aerosol cans", "drive less"). The remaining 88 subjects who we judged to have understood this question produced 155 responses (mean = 1.76), which were classified into 12 response categories, with an interrater agreement of 86%. Table II presents the categories mentioned at least once by 10% of subjects.

Consistent with their responses to the general causation questions, subjects frequently mentioned driving and the use of aerosol cans. A large portion of those subjects who drove or used aerosol cans may have cited this as a personal contribution. The third topic, air conditioning, may have reflected the energy needed to operate them or the CFCs they contain. Although these same subjects saw deforestation as the primary cause of global warming, only 7% mentioned the use of wood or paper products, and one person observed that they had "cut two trees in my yard."

[6] In the past CFCs were used as a propellant in aerosol spray cans but such use was discontinued in the United States in 1978. CFCs have also been used as a foaming agent in the manufacture of styrofoam, but this use too is being phased out.

[7] This association with tropospheric ozone was also seen by Kempton[(2)] but not by Bostrom *et al.*[(1)]

Cause	Mean DA +2 to -2	Distribution T, ≈T, ?, ≈F, F
Agricultural problems and starvation in many places	1.28	
Increase skin cancer	1.00	
Ecological disasters all over the world	0.97	
Shorter milder winters all over the world	0.95	
Cause sea level to rise	0.83	
More and larger storms all over the world	0.80	
Shortage of oxygen in the atmosphere	0.78	
Make the climate "steamier"	0.68	
Increase precipitation and humidity all over world	0.49	
Reduce photosynthesis	0.41	
War and large immigration problems	0.25	
The main cause of species extinction today	-0.35	

Fig. 3. Responses to closed-form questions about effects of global warming, rank-ordered by mean DA index. The full distribution of responses is displayed in the right-hand column. T means true; ≈T means probably true; ? means don't know; ≈F means probably false; F means false.

3.5. Effects

Figure 3 reports responses to closed-form questions about possible effects of global warming. The DA in-

Table III. Actions Most Frequently Cited as "the Most Effective Actions" that the Individual Respondent Could Take to Help Prevent Global Warming: Responses Were Provided to an Open-Ended Question that Asked for a List

Response	% mentioning
Reduce driving	43
Political actions	34
Personal awareness	25
Recycle	20
Reduce aerosol use	16
"Green" consumption	12
Save energy	11

dices differed significantly among one another [$F(7,1204) = 50.7$, $p < .001$, HSD = .17]. There was widespread assent to statements predicting such disastrous consequences of global warming as "agricultural problems and starvation in many places," "ecological disasters," and "increased incidence of skin cancer."

Some of the consequences in Fig. 3 are conceivable outcomes of *extreme* global warming. Hence, one might speculate that affirmation of these statements reflects accurate knowledge about global warming coupled with the belief (captured in Fig. 1) that the warming that has and will occur is large. This speculation is not supported by the similarly strong support for the *qualitatively* incorrect predictions of increase in skin cancer and with the belief that warming will lead to a shortage of oxygen in the atmosphere.[8] We suspect that people are predisposed to view any future ecological or political disaster as a plausible consequence of climate change.

Subjects generally agreed that sea-level rise is one result of global warming. While there is some controversy over the relative magnitudes of the contributions, many scientists expect thermal expansion of the oceans to be a large contributor. Many respondents of Bostrom *et al.*[1] cited only melting glaciers and ice caps. Our subjects, too, were far more likely to agree that "the primary cause of sea-level rise" would be ice melting at the poles (80% T or ≈T; DA = 1.14) than heating of the ocean's waters (28% T or ≈T; DA = −.22) [$F(1,176)=120.18$, $p < .001$]. Subjects generally agreed that a rise in mean sea level would increase the magnitude of storm surge incursions into coastal areas but rejected the possibility that New York might be flooded, although one subject added the note, "I sure hope so."

[8] According to Kempton,[2] the latter belief arises from the view that deforestation will result in a reduction of oxygen production from CO_2 by photosynthesis. Alternatively, these responses might be based on a disposition to accept that global warming will lead to generalized environmental catastrophe and, consequently, that almost any conceivable bad future may arise from global warming. This is a consequence of the good environmental practice heuristic, discussed below.

3.6. Response Strategies

Humans can respond to global warming through one or a combination of the strategies of *adaptation, abatement,* or *geoengineering.* We asked both open-form and closed-form questions about these strategies.

3.6.1. What Can You Do?

In response to the open-ended question, "If you personally decided to help prevent global warming, what are the most effective actions that *you* could take?" 157 subjects provided a total of 311 responses (mean=2.11). Responses were classified into 12 categories, with an interrater agreement of 75%. Table III shows the responses given by 10% or more of the subjects.

Consistent with their other responses, subjects most frequently proposed cutting back on their driving and their use of aerosol cans. Very few people suggested that they could reduce their energy consumption, although this would be the most effective personal response to limit climate change. Many proposed political actions, such as voting, writing to legislators, and becoming active in legislation. Frequent references to increasing personal awareness suggested that subjects are not comfortable with their present knowledge.

3.6.2. What Can the Government Do?

In response to the open-ended question, "If the United States government decided to try to prevent global warming, what are the most effective actions that it could take?" 169 subjects produced 447 responses (mean = 2.76). In total, 29 scoring categories (including 1 category with 16 unclassifiable responses) were devised. Interrater agreement was 87%. Table IV lists the areas mentioned by at least 10% of subjects.

Consistent with subjects' causal attributions, the largest number wanted the government to reduce the loss in biomass (a blanket term which we use to incorporate such options as stopping or reversing deforestation), to reduce automobile use, and to facilitate expanded use of public transportation. The most common action involving industry was reducing or controlling emissions, typ-

Table IV. Actions Most Frequently Cited as "the Most Effective Actions" the U.S. Government Could Take if It "Decided to Try to Prevent Global Warming": Responses Were Provided to an Open-Ended Question that Asked for a List

Response	% mentioning
Protect biomass	34
Stop or limit pollution	31
Reduce automobile emissions	30
Protect ozone layer, restrict CFCs (includes aerosol cans)	28
Reduce industrial emissions	19
Recycle	14
Facilitate public transport	13
Facilitate alternative energy	13
Nonspecific environmental legislation	11
Increase public awareness/ education	10

ically without saying exactly which ones. References to reducing pollution and recycling tended to be similarly vague. As might be expected, there were frequent irrelevant references to protecting the ozone layer. No one mentioned such specific policies as carbon taxes or CAFE standards (for increasing automobile MPG). Rather, the dominant wish seemed to be that government should do *something*. Only three people stated that the government should not get involved at all.

3.6.3. *Closed-Form Questions About Response Strategies*

For the closed-form questions, subjects evaluated 21 possible strategies for responding to global warming, which we had chosen to vary widely in feasibility. Figure 4 rank orders these strategies by belief in abatement (BA) index. The black bars in these distributions are the proportion reporting don't know (as opposed to no effect, which is white). These BA indices differed significantly among themselves ($F(20,3280) = 63.3, p < .001$, HSD = .10].

A majority of our subjects judged all but 4 of the 21 strategies as likely to be effective. Three of the four exceptions involved geoengineering. Consistent with subjects' causal attributions, forest preservation and restoration and ways of reducing CFC emissions were judged to be among the most effective strategies. Energy taxes, fuel switching, and energy-efficient lighting received only slim majorities.

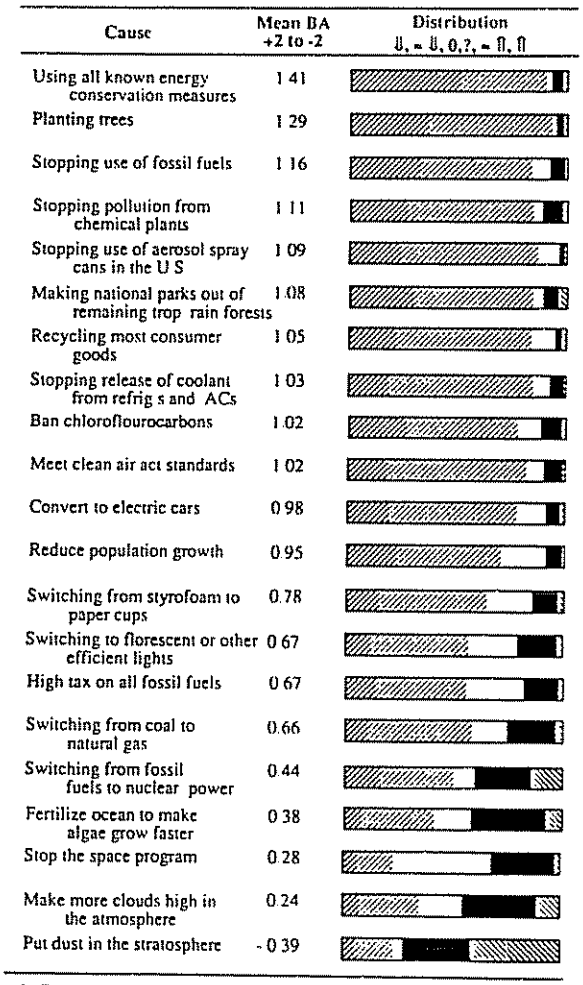

Fig. 4. Responses to closed-form questions about the likely impacts on global warming of various strategies, rank-ordered by mean BA index. The full distribution of responses is displayed in the right-hand column. ⇓ means will slow global warming; ~⇓ means will probably slow global warming; 0 (white bar) means no effect; ? (black bar) means effect unclear; ~⇑ means will probably speed global warming; ⇑ means will speed global warming.

While the very general strategies of adopting all known energy conservation strategies and stopping the use of fossil fuels were judged to be very effective, there was much less agreement about which specific strategies would be included. Switching to natural gas or nuclear power, two ways to reduce dependence on coal, received modest endorsement, as did increasing home energy efficiency by using fluorescent light bulbs or changing the market for efficiency by taxing fossil fuels.

Consistent with the widespread misconception that ozone effects are causally linked to global warming, people strongly believed that climate change could be

reduced by such ozone-related abatement strategies as stopping the use of aerosol cans in the United States and preventing the release of coolant fluids. Even switching from styrofoam cups and plates to paper was generally thought to have a positive effect. Fewer subjects thought that banning the use of CFCs altogether would reduce global warming than endorsed many of its supposed components, suggesting that they were unfamiliar with either the general term or its definition.

3.6.4. *Geoengineering*

Geoengineering involves modifying the physical properties of the earth or its atmosphere.[6] Subjects evaluated four such strategies. Planting trees and fertilizing the ocean are ways of absorbing greenhouse gases by creating new "carbon sinks." Making more clouds and putting dust in the stratosphere are two possible means of increasing albedo. Planting trees was highly favored, consistent with the strong belief that deforestation is a major cause of climate change. However, fertilizing the ocean and making more clouds were two of the least-favored options, while putting dust in the stratosphere was the only strategy for which more people judged there would be an increase rather than a decrease in global warming.

One possible reason for this skepticism is that subjects did not understand the mechanisms involved. Although subjects believed that the earth's temperature is influenced by both clouds and atmospheric dust, we did not ask whether they knew the *direction* of these effects. Thus, they may have rejected the geoengineering options because they believe that clouds and dust will *increase* the earth's temperature. A second possibility is that their fragmentary knowledge led them to reject unfamiliar options. This does not mean that they had to be familiar with an option in the context of global warming to find it acceptable—subjects frequently attributed the ability to slow global warming to actions whose positive environmental effects lie in quite different directions (e.g., reducing chemical plant emissions, recycling, increasing compliance with the U.S. Clean Air Act). A third possibility is that the geoengineering strategies (except for planting trees) seem "unnatural," or possibly even dangerous, because they involve increasing rather than decreasing human impact on the biosphere. Popular prescriptions for "saving the earth" usually call for reducing this impact (e.g., Refs. 7 and 8).

3.6.5. *Other Abatement Options*

Bostrom,[1] Kempton,[2] and Maharik and Fischhoff[9] all reported that some subjects saw a causal link between the space program and global warming or ozone depletion. Figure 2 shows that 20% of our subjects judged the space program to be a cause, and Fig. 4 shows that 23% thought that stopping the space program was likely to slow global warming.

Bostrom *et al.*[1] also reported several subjects who saw the use of nuclear power as a source of global warming. As shown in Fig. 4, 41% of subjects agreed with a statement to this effect. However, only 14% believed that switching to nuclear power would speed global warming, while 51% believed that such a switch would *slow* warming. The source of these apparent inconsistencies is unclear. In principle, this pattern of beliefs could be justified by someone who believed that nuclear power was a threat, but not as big a threat as fossil fuel energy sources.

4. DISCUSSION

Two simple facts are essential to understanding the issue of climate change.

1. If significant global warming occurs it will be primarily the result of an increase in the concentration of carbon dioxide in the earth's atmosphere.
2. The single most important source of carbon dioxide addition in the earth's atmosphere is the combustion of fossil fuels, most notably coal and oil.

The relatively well-educated laypeople we interviewed did not have a clear understanding of these facts. Their mental models of the climate issue were encumbered with a large number of secondary, irrelevant, and incorrect beliefs. As a result, risk communication, designed to help such laypeople participate in ongoing national debates on this topic, should stress these two simple facts and their implications. In order to do so, such communications should directly address the misunderstandings that are most likely to result in incorrect inferences, namely,

- confusion with the problems of stratospheric and tropospheric ozone and
- general blurring with other environmental problems.

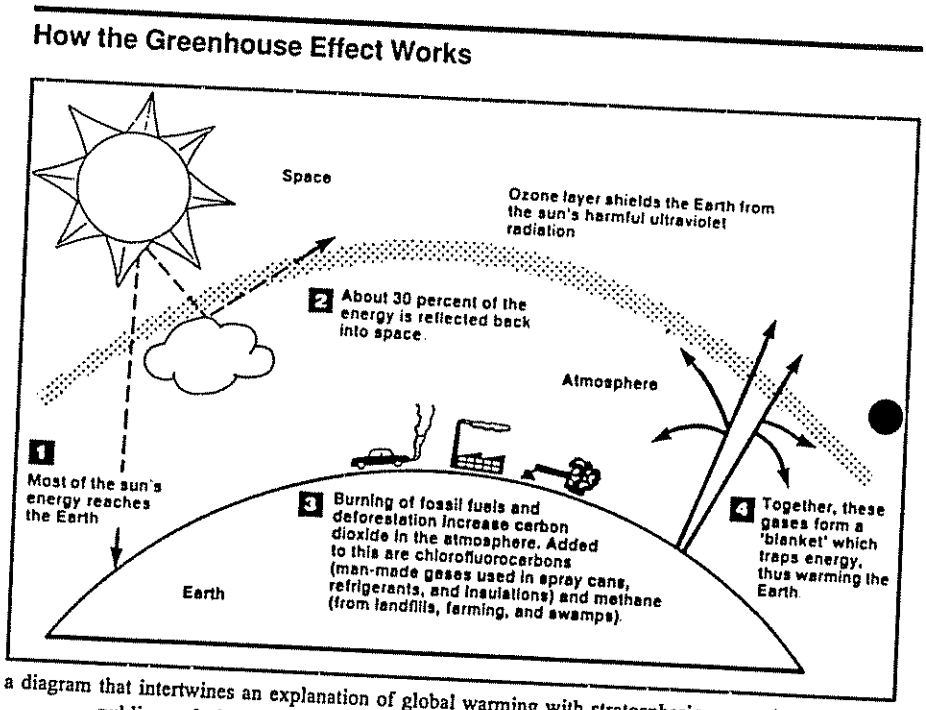

Fig. 5. Example of a diagram that intertwines an explanation of global warming with stratospheric ozone depletion, possibly contributing to public confusion about the two topics. Reprinted with permission from Ref. 11

4.1. Confusion with Ozone

Previous researchers have found widespread confusion between the effects of stratospheric ozone depletion and global warming.[1,2,10] Such confusion seems to lead people to favor such suboptimal, or even irrelevant policies as stopping the use of aerosol cans and changing from paper to styrofoam cups. Consequently, ozone confusion may lead people to invest their energies in these futile activities, as well as to believe that problems are being solved when they are not.

One reason for this confusion may be that popular articles often discuss both problems together. Even when writers conscientiously distinguish between the effects, the very fact of frequently hearing about them simultaneously may lead people to form an association between them. An example of such potential miscommunication is shown in Fig. 5.[11] While this figure contains no literal errors of fact, it could create confusion by including a prominent depiction of the ozone layer in an illustration of the greenhouse effect.[9] Moreover, both the radiation being reflected back from the sun ("point 2") and the trapping of energy by greenhouse gases ("point 4") are depicted in a way that could lead naive readers to infer interactions with the ozone layer. In fact, one might easily conclude that the ozone layer and the energy-trapping "blanket" are essentially the same thing.[10] Finally, emphasis is given to CFCs in the brief description of greenhouse gases ("point 3"). Such linkage in the mental models of laypeople is likely to lead to a seriously flawed public discussion of policy options.

4.2. Good Environmental Practice

Our respondents attributed climate change to a variety of environmentally unfriendly causes, attributed a diversity of effects to climate change, and believed that most of the environmentally friendly actions offered would reduce climate change. We suspected that judgments about climate change may be based on beliefs about what constitutes good environmental practice. That is, in the absence of specific information, subjects default assumptions may be that things which seem bad for the environment also cause global warming, while

[9] As we explain in Part 1 in this series,[1] the issues of CFC ozone depletion and global warming are in some ways linked, but this is a level of subtlety that is not required for a basic understanding of either problem and clearly does not underlie either the confusion in lay mental models or risk communications such as the one illustrated in Fig. 5.

[10] One subject in the Bostrom *et al.*[1] study, when discussing the definition of climate change, referred to "heat being trapped between the ozone layer."

Causes (retabulated from Table II)

	Plausible cause (Code = 1)			Implausible Cause (Code = 0)		
		DA	Rank		DA	Rank
Neutral or good environmental practice (code = 1)	Cows, rice paddies, termites and swamps	-.04	11	The space program	- 69	12
		-.04	11		- 69	12
Poor environmental practice (code = 0)	Clearing rainforest	1.42	1	Aerosol spray cans	1.16	3
	Deforestation	1.37	2	The hole in the ozone layer	.80	6
	Burning fossil fuels	1.12	4	Toxic wastes	.77	7
	Ozone in cities	1.10	5	Ocean dumping	.17	8
		1.25	3		.60	7.2

Response strategies (retabulated from Table VI)

	Plausible abatement (Code = 0)			Implausible abatement (Code = 1)		
	Cause	BA	Rank	Cause	BA	Rank
Good environmental practice (code = 1)	Using all energy conservation measures	1.41	1	Stopping pollution from chemical plants	1.11	4
	Planting trees	1.29	2	Stopping the use of aerosol cans in the U.S.	1.09	5
	Stopping fossil fuel use	1.16	3	Recycling consumer goods	1.05	7
	Preventing coolant release	1.03	8	Compliance with clean air act	1.02	10
	Banning CFCs	1.02	9	Converting to electric cars	.98	11
	Reducing population growth	.95	12	Changing from styrofoam to paper	.78	15
	Using efficient lighting	.67	14			
	Mean	1.08	6.71	Mean	1.00	9.17
Poor environmental practice (code = 0)	Changing from coal to natural gas	.66	13	Stopping the space program	.28	20
	Adopting nuclear power	.44	17			
	Fertilizing the ocean	.38	18			
	Putting dust in the stratosphere	- 39	20			
	Mean	.26	17.1	Mean	.28	20

Fig. 6. Partition of causes of climate change (above) and responses to climate change (below) along the dimensions of "environmental practice" and "scientific plausibility." For the former dimension, causes are classified as reflecting either "poor" or "good or neutral" environmental practice, while responses are classified as reflecting either "good" or "poor or neutral" environmental practice.

environmentally friendly actions reduce global warming.

On a *post hoc* basis, we divided both the causes and the abatement options into two dichotomous categories according to (a) whether they reflect good environmental practice and (b) whether they are plausibly related to global warming. Figure 6 presents these partitions. The top half of the figure shows that subjects were most likely to agree with causes that both constitute poor environmental practice and are scientifically plausible. However, they also implicated many implausible causes that we classified as poor environmental practices. Similarly, in the lower half of Fig. 6, their strongest endorsements were for strategies that were good practice.

We regressed DAs (for causes) and BAs (for abatement) onto these two categories. For both analyses, the two predictors were coded as dummy variables as indicated in Fig. 6 (e.g., "clearing tropical rainforests" was assigned a code of 1 for *plausibility* and 0 for *good*

environmental practice). The resulting regression equations are as follows:

BA (causes) = −.64 − 1.35 (good practice) + .552 (plausibility)

DA (abatement) = .23 + .784 (good practice) + .055 (plausibility)

In both cases, the proportion of variance accounted for by the equation was highly significant (causes R^2 = .82, abatement, R^2 = .63; both F's > 15, p <.001). For causes, both plausibility (t = 5.88) and good practice (t = 3.00) contributed significantly to the prediction. For abatement, however, while good practice accounted for a significant amount of the DA variance (t = 5.45), plausibility did not (t = .42). These results raise the possibility that some of our subjects' correct beliefs may have been right for the wrong reasons, in that they were fortuitously correct inferences from what they see as good environmental practice. Of course, such *post hoc* analyses are highly speculative. In future work, this suggestion should be subjected to a more rigorous test.

4.3. Conclusion

Laypeople display a variety of misunderstandings and confusions about the causes and mechanisms of climate change. Both the United States and the rest of the world are currently considering policy responses to the issue of climate change which would entail costs and expenditures amounting to trillions of dollars. U.S. society cannot have intelligent democratic debate on these choices unless lay mental models are better informed. Fortunately, the clarifications needed to produce adequate public understanding appear to be well within the capabilities of modern risk communication.[12,13] We are currently working on the development and evaluation of such material.

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