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Climate Change Conceptual Change:

Scientific Information Can Transform Attitudes

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Abstract

Of this article's 7 experiments, the first five demonstrate that virtually no Americans know the basic global warming mechanism. Fortunately, Experiments 2-5 found that 2-to-45 minutes of physical-chemical climate instruction durably increased such understandings. This mechanistic learning, or merely receiving seven highly germane statistical facts (Experiment 6), also increased climate change *acceptance*—across the liberal-conservative spectrum. However, Experiment 7's misleading statistics *decreased* such acceptance (and dramatically, knowledge-confidence). These readily available attitudinal and conceptual changes through scientific information disconfirm what we term "stasis theory"—which some researchers and many laypeople varyingly maintain. Stasis theory subsumes the claim that informing people (particularly Americans) about climate science may be largely futile or even counterproductive––a view that appears historically naïve, suffers from range restrictions (e.g., near-zero mechanistic knowledge), and/or misinterprets some polarization and (non-causal) correlational data. Our studies evidenced *no* polarizations. Finally, we introduce HowGlobalWarmingWorks.org—a website designed to directly enhance public "climate change cognition."

Climate Change Conceptual Change:
Scientific Information Can Transform Attitudes

People are well-informed about various topics, but *some* scientific knowledge has not infused non-specialists' minds, let alone the minds of a political majority. We assess public ignorance regarding climate science's physical/chemical mechanisms (Ranney, Clark, Reinholz, & Cohen, 2012a; cf. Arnold, Teschke, Walther, Lenz, Ranney, & Kaiser, 2014, and Shepardson, Niyogi, Choi, & Charusombat, 2011), and explicate attempts to rapidly fill that void with foundational theory and statistical evidence for anthropogenic global warming (i.e., Earth's human-caused rise in mean temperature).[1] We herein describe seven recent experiments[2]—and a web-site—that together both demonstrate this dearth of public knowledge and offer ways to address/diminish it.

In our studies, (a) Experiment 1 exhibits the widespread mechanistic knowledge void, (b) Experiments 2-5 show the utility of explaining global warming's mechanism (thrice with delayed posttests), (c) Experiment 6 addresses the benefit of statistical feedback in making global warming more obvious, and (d) Experiment 7 exhibits control over the latter phenomenon by reversing the effect—that is, obscuring global warming's reality with cherry-picked, misleading statistics. Finally, we introduce a website by Ranney, Lamprey, Reinholz et al. (2013), www.HowGlobalWarmingWorks.org, which implements some of these lessons to help quickly reduce the general public's global warming "wisdom deficit" (Clark, Ranney, & Felipe, 2013).

As background for these studies and the website, please note that we view what we call the "climate change cognition" field (Ranney, Lamprey, Le, & Ranney, 2013) as being gripped by a false dichotomy between whether one's knowledge or one's "culture" determines whether one accepts global warming as occurring and/or anthropogenic. Many psychological dichotomies resist eradication, even given clear synergies between "sides," as with the ancient nature-nurture[3] "dichotomy." But the notion that culture either totally or largely trumps both scientific narratives and evidential resources when one forms one's climate-change attitudes yields a false *culture-information* dichotomy.[4] What we call "stasis theory" is the idea that one's cultural context (e.g., political party) overwhelmingly dominates flexible learning from objective scientific information/regularities.[5] We argue that, like nature and nurture, culture and science knowledge *interact*; this seems obvious to many, but some others are not yet convinced.

Although this article highlights roles for empirical information (spanning crucial statistics and "chain-and-transit" physical mechanisms), we certainly believe that ignoring culture is a mistake. Indeed, Ranney and his colleagues have highlighted and demonstrated culture's importance (e.g., religion, nationalism, and military history) in studies utilizing his six-construct Reinforced Theistic Manifest Destiny theory (RTMD; e.g., Ranney, 2012; Ranney & Thanukos, 2011). Information and knowledge rarely accrue in cultural or framing vacuums (McCright, Charters, Dentzman, & Dietz, in press; McCright & Dunlap, 2011), just as new data and scientific framings affect culture: Science and culture synergistically determine belief.

While culture influences scientific discovery and communication, culture also *mutates* as science progresses. Extant climatological evidence/theory is so potent that we expect that those who deny global warming's presence or anthropogenicity will continue to dwindle (a) as its effects become increasingly obvious (e.g., less ice and biodiversity, but increased droughts), (b) as climate measurements become increasingly unassailable, and (c) as now-young adults become more dominant politically (because the young generally accept anthropogenic climate change more fully than their elders). Such societal progressions have occurred historically in spite of powerful suppression attempts, as with the acceptances of heliocentrism, our spherical Earth, and tobacco-illness links (e.g., Oreskes & Conway, 2010; Proctor, 2012). Yet in privileging culture and articulating the main part of the stasis view, Kahan recently (2013b, p. ED32A-08) wrote, regarding the "public conflict over climate change," that "efforts to promote civic science literacy can't be expected to dissipate such conflict."

Given our observations of significant changes after boosting science literacy, in the medium-to-long run, we believe the *opposite* of stasis theory (Clark, Ranney, & Felipe, 2013)—specifically, we hold that informing people about climate science can/does indeed play an important role in mobilizing action to respond appropriately to, and mitigate, climate change. Although scientists might fear that climate change will meet the 150-year "fighting retreat" that has faced evolution, climate change's effects will be saliently speedier than speciation-yielding processes. Further, denying evolution yields less harmful impacts than denying anthropogenic climate change (e.g., Ranney, 2012); denying species-change has few blatant consequences, even for most farmers. But coastal residents denying climate change may be complicit in their land becoming seabed. More directly, stasis is disconfirmed by recent history, namely the rapid increases in anthropogenic global warming acceptance in postindustrial nations—even rising to 81% in the U.S. (Davenport & Connelly, 2015) from virtually 0% a few decades ago—despite few recent changes in political rhetoric (cf. since "An Inconvenient Truth" was released).

Mechanistic Knowledge is Special

Although some measures of science knowledge do not always correlate with normative acceptance in all researchers' studies, not all knowledge is equally germane regarding beliefs. *Mechanistic* knowledge, especially about global warming, is critical and perhaps paramount in determining a particular scientific position's acceptability. Specifically, mechanistic knowledge can "break ties" among contentious positions if initial information spawns ambivalence. For instance, one encounters popular-press whirlwinds regarding evolution (often about societal controversy; e.g., Ranney, 2012), yet one rarely sees cogent media descriptions of evolution's mechanism (e.g., mutation, variation, natural selection, etc.). Anthropogenic global warming likewise triggers media whirlwinds—generally of claims about current or projected climate effects (e.g., sea acidification, species' reductions, etc.). However, the public virtually never sees cogent scientific explanations of global warming's mechanism. If *you* were to explain its chemical/physical mechanism, could you? Please try this for 40 seconds before reading further.

If you are like virtually all of our pilot studies' subjects, you could not answer our question with even basic accuracy. Yet we might expect scientifically literate people to produce a brief, mechanistic, global warming explanation—as in these 35 words: "Earth transforms sunlight's *visible* light energy into *infrared* light energy, which leaves Earth slowly because it is absorbed by greenhouse gases. When people produce greenhouse gases, energy leaves Earth *even more slowly*—*raising* Earth's temperature." (These two sentences are at Appendix A's end—and from Ranney, Clark, Reinholz, & Cohen, 2012b.) If you failed to capture this mechanism's critical elements, you are hardly alone; we have queried environmental scientists and climate-communication experts who were distressed upon failing to generate what the 35 words contain. Our (Ranney et al., 2012a) mechanistic knowledge-assessment items followed years of piloting through conversations with dozens of chemists, biologists, geologists, cognitive scientists, and social scientists—including many (e.g., frequently-publishing climate change communicators) who admitted to not knowing global warming's mechanism, even at the 35-word level.

Of course, while many Americans align with their climatologists' mechanism-informed consensus, others may align with conservative radio/television hosts; this part of "cultural cognition" we do not dispute. If those from opposing "camps" meet and engage the evidential (rather than the mechanistic) basis that is more commonly familiar, the discussion often devolves into (a) appeals to competing authorities (e.g., “ties” among politicians, scientists, or media personalities), and/or (b) methodological or evidential-validity questions—perhaps including the motives of the researchers or those denying global warming. Impasses may involve data (e.g., whether Earth’s temperature still rises), technique (e.g., carbon-dating, heat-sensors’ positionings, etc.), or bias (e.g., grant-seekers vs. fossil fuel industrialists).

In contrast, mechanistic knowledge (see the 35 words above) focuses on the *how*, which allows for superior interpretations of global warming’s evidence. The mechanism explains causal relationships—among energy, sunlight, infrared light, earth’s surface, temperature increases, and greenhouse gases (with their anthropogenic additions). However, this normative mechanism also crucially highlights the lack of an “other side” mechanism: if asserting that increased greenhouse gas emissions is *not* problematic, one who denies global warming ought to explain either flaws in the scientific consensus’s mechanism, an alternative mechanism, or how the scientific mechanism is parametrically inconsequential (e.g., that climate sensitivity is low). The mechanism essentially demands a denier to answer this: “If non-natural greenhouse gases chemically increase Earth’s temperature, *how* can anthropogenic additions be negligible?”

Others, and we, have found that mechanistic explanations aid reasoning. For instance, Fernbach, Rogers, Fox, and Sloman (2013) showed that soliciting mechanistic explanations usefully reduces subjects’ illusions of explanatory depth, yielding more appropriately moderated attitudes and more political donations; Fernbach, Sloman, St. Louis, and Shube (2013) found that at least a shallow level of explanatory detail helps people appreciate superior products’ natures.

We next report the first of seven studies that each regard relationships between global warming knowledge and acceptance. One might hope that the aforementioned failures of even professional scientists to correctly explain global warming's mechanism are rare, if embarrassing, anecdotes (yet see Libarkin, Miller, & Thomas, 2013), but we hypothesized that public knowledge would also be poor—so, in moving beyond the piloting stage we conducted Experiment 1's diagnostic survey, which yielded a keystone phenomenon for all that follows.

Experiment 1: Assessing Global Warming Mechanistic Knowledge

Experiment 1 sought to ascertain the populace's current state of knowledge about global warming's physical/chemical mechanism. In contrast to most other documented global warming comprehension difficulties (e.g., Shepardson et al., 2011), Experiment 1 thus addressed less-studied difficulties in *mechanistic* understanding. We strove for much greater detail in engaging and assessing mechanistic aspects than found in prior studies that often rely heavily on recognition items (cf. Kahan et al., 2013, Kahan et al., 2015, McCright et al., this issue, and Sundblad et al., 2007—e.g., regarding how CO_2 and other greenhouse gases *perhaps somehow* cause warming or "trap" heat). These other studies usually omit mention of the greenhouse effect (with Tobler, Visschers, & Siegrist, 2012, as an exception), and none approach even the aforementioned 35 words' level of detail. For instance, "infrared" never seems to appear—and is rarely seen in federal climate-change public-information documents; indeed, any energy/light transformation notion seems absent in other experiments. Experiment 1's central hypotheses were that mechanistic understanding is (1) modest, yet (2) related to acceptance/attitudes.

Method

Subjects, Design, and Procedure. We collected 270 surveys from politically diverse visitors to San Diego parks (e.g., Balboa Park and Santee Lakes; n = 201) and community college students (n = 69). (To eliminate cross-national cultural effects and ensure English competence, each of this article's studies excluded subjects who were not long-term U.S. residents.)

Democrats comprised 39.3% of the sample—similar to national norms when allowing responses beyond the main two parties. The plurality (or majority, depending on subroup) of subjects were also under age 30, female (59%), Christian, having had some college, and desiring or having children. Alternately seated park visitors received a $5 gift cards for participating; community college (chemistry and humanities) students volunteered during scheduled class breaks.

Materials. The 10-15 min. survey included: (a) 20 policy-preference Likert items, (b) two global warming belief items, (c) six short-answer global warming knowledge items (scored with a rubric yielding high inter-rater reliability; mean $\kappa > .7$), (d) 13 items about global warming's possible causes, (e) four items on subjects' willingness to make personal climate sacrifices, and (f) nine demographic questions. (Supplemental Materials' Appendix S1, etc., offers more detail.)

Results and Discussion

As predicted, subjects rarely understood global warming's mechanism (as scored by the aforementioned rubric; Cohen, 2012). In explaining that mechanism, only 12% of them exhibited partial understanding by referencing atmospheric gases trapping heat. Merely 3% of subjects named the greenhouse effect. Only 1% attempted to differentiate types of energy/light. *No one* (0%) correctly mentioned light absorption, or the input/output asymmetry involving visible and infrared light—the crux of greenhouse-effect knowledge. The median and mean understanding scores were 0 and .65 (out of 3). Misconceptions were prevalent: for instance, 16% asserted that atmospheric (e.g., ozone) destruction caused global warming (cf. Bord, Fisher, & O'Connor, 1998), and 74% incorrectly blamed ozone depletion as a major cause of global warming.

Despite this mechanistic ignorance, 80% of subjects accepted global warming and 77% accepted its significantly anthropogenic origins. More crucially, though, those knowing the most generally accepted global warming the most: scored mechanistic knowledge significantly correlated with one's global warming acceptance as occurring (r = .22, p = .0002) *and* anthropogenic (r = .17, p = .005). Suggesting that such knowledge is behaviorally potent, anthropogenic climate change acceptance was significantly associated with sacrifice-willingness for *all four* willingness-to-sacrifice items ($\chi^2(4) > 32$, $p < .001$)—and subjects' knowledge scores significantly associated with *two* of those four items ($\chi^2(1) = 3.9$, $p < .05$, and $\chi^2(1) = 16.7$, $p < .001$, the latter surviving four-comparison Bonferroni correction).[6]

Our subjects—even those accepting global warming's reality—clearly knew little about global warming's (or the greenhouse effect's) mechanism. But such knowledge *was* related to acceptance *and* willingness to sacrifice. This, and other studies' results below, seem to contradict Kahan et al. (2012), whose data suggest that *general* science literacy measures may not predict global warming attitudes across the population[7]—but note that our measures are specific to (particular) *climate* literacy. Finally, we found that accepting global warming, even absent the science knowledge, is associated with climate policy attitudes that reflect scientific consensus.

Such associations are replicable, as our experiments below show. Beyond these, a separate multi-site project that we are collaborating in has more recently also found another (U.S.) link between mechanistic knowledge and global warming acceptance—both anthropogenic and existential acceptance. Relatedly, Arnold et al. (2014) translated Experiment 1's study and scoring materials and, with Germans, have replicated Experiment 1's links between *mechanistic* knowledge and (a) global warming acceptance, (b) anthropogenic climate change acceptance, and (c) general environmental attitudes (with the General Ecological Behavior scale; GEB). With a separate sample of hundreds of more Germans, the correlations were replicated again—even after knowledge interventions were received (including Experiments 2-5's 400 words)—and were replicated for both immediate and one-month-delay post-intervention tests. Initial German mechanistic knowledge, like the Americans', was low—only 18% accuracy (1.6 on a 0-9 scale)–– yet Arnold et al. also found such knowledge related to self-reported environmental attitudes.

Experiment 1 (first reported in Ranney et al., 2012a) contributes to the growing evidence that—counter to stasis theory—acceptance and *specific* climate change knowledge are correlated. For example, while not examining *mechanistic* knowledge, Guy, Kashima, Walker, and O'Neill (2014) report that 335 Australians' knowledge about activities that increase atmospheric greenhouse gases correlates with acceptance that climate change is occurring; Guy et al. note that "the small literature on specific climate change knowledge" (such as Swedes studied by Sundblad, Biel, & Gerling, 2007, and Swiss subjects studied by Tobler et al., 2012) indicates that climate change knowledge correlates with beliefs aligning with scientific evidence. Likewise, Stevenson et al. (2014), while not specifically assessing mechanistic knowledge (but for one item, of 19, that involved greenhouse gases inhibiting Earth's heat-escape), report a correlation between climate knowledge and anthropogenic global warming acceptance—for both individualists and communitarians—among 378 North Carolina adolescents. In sum, contrary to stasis theory (e.g., Kahan et al., 2012), the above scholarship alone represents ten separate studies, spanning five countries and three languages, that link climate change acceptance and knowledge (with four specifically focusing on mechanistic global warming knowledge; for an eleventh study, see Otto & Kaiser, 2014).

Our years of interviewing experts, and Experiment 1's findings, cohere with Libarkin, Miller, and Thomas's finding (2013, p. ED32A-05) that university "geoscientists" (college majors through professionals) held only "slightly more sophisticated greenhouse effect models than entering freshmen." The "wisdom deficit" (Clark, Ranney, & Felipe, 2013) found in

Experiment 1 informed Experiments' 2-6's materials, as we sought to make the (unfortunately) "secret knowledge" for *justified* global warming acceptance both memorable and actionable.

Preface to Experiments 2-5, the Mechanistic Knowledge Interventions

Having established the knowledge-acceptance link, Experiments 2-5 use interventions to assess whether increasing subjects' mechanistic global warming knowledge *causes* greater global warming acceptance.[8] Experiments 2-5, although not their main foci, replicate Experiment 1's finding that people do not understand global warming's mechanism. As Experiment 1 also showed that mechanistic knowledge is clearly related to one's willingness to sacrifice (which Arnold et al., 2014, replicated), it further motivated us to develop Experiments 2-5's materials that were intended to improve people's understandings of the basic physical-chemical global warming mechanism. As noted earlier, mechanistic knowledge seems unlike other—say, randomly sampled—domain knowledge (e.g., other knowledge such as reasons for one's position, as Fernbach, Rogers, Fox, & Sloman, 2013, show); its special, tie-breaking, knowledge helps one decide which "side" of a scientific contention is likely most correct. The importance of mechanistic knowledge about climate change, both theoretically and empirically (e.g., from Experiment 1) led us to attempt "wisdom-enhancing" interventions. Experiments 2–5 all address the utility of explaining global warming's mechanism and we hypothesize that people will (1) understand and significantly retain the information—perhaps with notable longevity—and (2) adopt attitudes and beliefs more aligned with the scientific consensus's mechanistic explanation (e.g., Lewandowsky, Gignac, & Vaughan, 2013; Maibach, Leiserowitz, & Gould, 2013).

Experiment 2: Dramatic Mechanistic Learning and Increased Global Warming Acceptance

In prior research on physics cognition, explanatory coherence, and the Numerically Driven Inferencing paradigm (NDI; e.g., Garcia de Osuna, Ranney, & Nelson, 2004), we found that small amounts of crucial information can yield considerable conceptual changes—even changes in attitude and acceptance. Within such paradigms, subjects typically predict a phenomenon or statistic and later receive veridical feedback; they "put their cards on the table" before the feedback, so hindsight bias and post-hoc rationalization are inhibited—and belief change is increased (e.g., Rinne, Ranney, & Lurie, 2006). Here we report on a similarly compact and empirically grounded intervention with a 400-word text that includes, and expands upon, the three key conceptual pieces exemplified by the 35 words quoted earlier. Appendix A displays the 400 words, which were carefully written in conjunction with—among other Berkeley colleagues/experts—Drs. Ronald Cohen (an atmospheric physical chemist), Daniel Reinholz (a science and mathematics educator), and Lloyd Goldwasser (a zoologist/climate-educator).

Method

Subjects, Design, and Procedure. Experiment 2's subjects were 85 University of California (Berkeley; UCB) cognitive science undergraduates and 41 University of Texas-Brownsville (a 90%-Hispanic institution) geoscience undergraduates who completed the study as requested (with checks for coherent responses) and were decade-or-more U.S. residents; women represented 52% and Democrats a plurality. (Subjects were randomly assigned to either a "pretest-and-posttest" or "no-pretest" group, but we omit discussing the no-pretest group, which represented a between-subjects control—unnecessary, in the end—for an experimenter demand effect; see Ranney et al., 2012a for more.) Subjects (1) provided global-warming explanations and filled out knowledge and attitude surveys, (2) read the 400-word explanation of global warming's mechanism and rated their experienced surprise, (3) were re-tested (identically to the pretest) on their knowledge and attitudes, and (4) answered demographic questions.

Materials. Our attitude survey included twelve items regarding global warming on 1–9 scales. Self-reports of knowledge also involved a 1–9 scale. *True* global warming knowledge was assessed through written responses to three queries and (on the posttest only) two fill-in-the-blank items regarding visible and infrared light. The three written-response queries elicited explanations about (1) how global warming works (so a high-school senior could understand it), (2) differences in how energy/heat/light travels from the sun to Earth versus travels away from Earth, and (3) what makes something a greenhouse gas (if not all gases are greenhouse gases); inter-rater reliability of scored queries was again high: mean $\kappa = .7$. (The Supplemental Materials' Appendices S2 and S3 offer more detail.)

Results and Discussion

Replicating Experiment 1, even our relatively scientifically sophisticated samples initially exhibited diminutive greenhouse-effect mechanistic understandings—exhibiting inaccuracies (re: ultraviolet light, ozone-layer depletion, non-greenhouse-gas pollution, and incoming light's reflection, etc.). Furthermore, *zero* pretest explanations (0%) mentioned different light/radiation types or atmospheric retention time, despite prompt #2 (to contrast energy going to/from Earth); after reading our 400 words, though, most subjects (59%) correctly answered that Earth emits *infrared* light ($p < .0001$). We analyzed key scored qualitative explanations regarding (a) light entering versus exiting Earth, (b) greenhouse gases' radiative interactions, and (c) increased atmospheric energy-retention time—and found dramatic knowledge increases (a doubling-to-tripling) for each: (a) 20% to 56%, (b) 27% to 63%, and (c) 19% to 48%, respectively when averaging over both populations (p's $< .01$ for (a) and (b) subscores *separately* for Berkeley *and*

Brownsville subjects; *p*'s < .05 for the same tests for (c)). Crucially, global warming acceptance also increased after our brief intervention (Brownsville: $t(39) = 4.24$, $p < .0001$; Berkeley: $t(72) = 2.28$, $p = .01$), with subjects shifting, on average, 14% closer to "extreme" acceptance.[9, 10] (Pretest *self-perceived* knowledge ratings and global-warming attitudes significantly correlated among Berkeley—$r = .39$, $p = .01$—but not Brownsville, students: $r = .15$, $p = .55$.)

Experiment 2 thus extended and replicated Experiment 1's (internally replicated) findings––and replicated prior pilot interviewing. Well-educated people from two culturally/ethnically distinct geographies displayed little initial mechanistic global-warming knowledge. Only 400 words later, though, in under two minutes, dramatic increases were observed in mechanistic knowledge with notable increases in global warming acceptance. Experiment 3 was designed to again replicate this intervention effect and Experiments 1-2's "modest initial knowledge" findings—as well as to start assessing the intervention's longevity.

Experiment 3: Online Replication and Longevity Extension

How durable are Experiment 2's attitude changes? Experiment 3 probed for such changes about four days post-intervention. In addition, to assess the intervention-effects' generalizability beyond college-classroom settings, we provided it online—testing whether attitude changes obtain without experimenter observation, on subjects' own computers.

Method

Subjects, Design, and Procedure. We concurrently extended an assessment of Experiment 2's phenomena's (a) longevity (through delay) and (b) format-sensitivity (i.e., online, using Qualtrics); otherwise, Experiment 3 was effectively the same as Experiment 2. About half (38) of Experiment 3's 80 UCB (58% female) psychology undergraduates were pretested an average of 18.5 days *pre*-intervention—to allay test-retest effects—although Experiment 2 found little evidence for them. A plurality indicated no party affiliation (choosing "none"). (We again employed a randomized "no pretest" condition [n = 42] for a successful experimenter-demand check, but do not discuss it here; see Clark, 2013.) Subjects received a delayed posttest 1–8 days ($M = 4$) post-intervention—a range planned to assess the retention timecourse for later studies.

Materials. Experiment 3 further enhanced Experiment 2 (and its 400-word stimulus) by adding three objective items to the immediate posttest regarding surprise and embarrassment. (The Supplemental Materials' Appendix S4—and Clark, 2013—offer more detail.)

Results and Discussion

The results replicated Experiment 2's—and extended them by finding that post-delay gains remained. Scored knowledge again correlated with self-rated knowledge ($r = .5$, $p < .0001$), to roughly the same degree found for Experiment 2's UCB students. On 0-to-9 scales, scored knowledge soared from 3.8 (pretest) to both 6.5 (posttest) and 6.3 (delayed posttest)—robustly significant gains (z's > 9.5; p's < .00001) with no significant forgetting. Stated global warming acceptance yielded a similar pattern: mean ratings rose from 6.20 (pretest) to 6.54 (posttest) and were mostly retained at 6.44 (delayed posttest)—notable[11] gains (again) for a 400-word text (immediate posttest: $t(79) = 2.5$, $p = .006$; delayed posttest: $t(79) = 1.7$, $p = .05$). The largest posttest global-warming agreement-gains arose from items assessing (a) certainty of global warming's occurrence and (b) humans largely causing it (.19 and .25 gains, respectively). Likewise, subjects' mean self-rated knowledge increased markedly from pre- to post-test (4.5 to 5.6; also replicating Experiment 2)—and yielded a delayed posttest gain that was also robustly significant ($M = 5.2$; both post-tests' gains' yielded z's > 5.9; p's < .00001).

In sum, Experiment 3 extended our finding that well-considered information, even received online, increases anthropogenic global warming acceptance and behaviorally relevant attitudes.

Further, the 400-word-induced conceptual changes have some longevity. Because computer-based interventions often scale well, enhance reliability, and prove cost-effective, Experiment 3 inspired www.HowGlobalWarmingWorks.org discussed below, a wider online dissemination of mechanistic, and other, global warming information. It next seemed apt (for Experiment 4) to broaden our samples' representativeness, thus more directly assessing whether our information might trigger polarization[12] phenomena that have concerned others (e.g., Kahan et al., 2012; cf. Lord, Ross, & Lepper, 1979).

Experiment 4: A More General Mechanistic Replication with Mechanical Turk (MTurk)

Experiment 4 replicates and extends Experiments 2-3. This was done by engaging a more nationally reflective (Amazon MTurk) sample *and* a longer delay.

Method

Subjects, Design, Procedure, and Materials. At 58% Democratic, our 41 subjects (45% female) were over-represented to about the same degree as is typical of MTurk samples (Richey & Taylor, 2012; see Clark, 2013). Mean self-rated conservativism was 3.9 (of nine) points, comparable to our other experiments' (albeit undergraduate) means. Three subjects were excluded (a) after automated methods identified verbatim copying from the web (although subjects knew that accuracy was unrelated to compensation), (b) due to violated requirements (e.g., regarding long-term U.S. residency), or (c) due to blatant self-*in*consistency, as checked for all our experiments. Of the 38 retained subjects, 28 also completed our delayed posttest, which occurred after 4–11 (M = 5.5) days. The materials, procedure, and design—other than increasing the delay and deleting the "no pretest" condition (given prior findings rendering it moot) closely followed Experiment 3's—again using the 400-word mechanistic explanation as the intervention.

Results and Discussion

This intervention replicated and extended Experiments 2–3's results, as shifts in attitudes and beliefs were retained over the 5.5-day mean delay: Scored mean knowledge was comparable to previously tested non-University subjects, but dramatically and significantly jumped from a paltry 1.9 at pretest to 4.8 at posttest and 3.9 at delayed posttest (on a 0–9 scale; z's > 3.3, p's < .001). Global warming acceptance ratings increased significantly from a 6.3 pretest mean to a 6.6 posttest mean ($z = 3.45$; $p = .001$)—and the delayed posttest's score was maintained ($M = 6.6$, $z = 2.84$; $p < .005$). When asked about *post-hoc* embarrassment or surprise regarding their (usually lacking) mechanistic knowledge, subjects' mean rating was 4.1 on its 1–9 scale.

Notably, the correlation between conservativism and mean global-warming acceptance gains was *not* significant and basically zero ($r = -.03$, $p = .85$), indicating *no* polarization. Indeed, of the eight most conservative subjects, five increased their global warming acceptance, and only one (slightly) reduced his/her acceptance. Experiments 6 and 7 below offer similar non-polarization evidence (cf. Kahan et al., 2012); but now we turn to the final, most elaborate, mechanistic intervention study—and one that greatly expanded our retention delay.

Experiment 5: A More Extensive Intervention With a Greater Longevity

Experiments 2-4 thrice demonstrated our 400-word explanation's utility, so we turned to (a) expanding the brief intervention into more of a curriculum, (b) expanding the resultant intervention's longevity assessment, and (c) deploying the intervention in a more standard instructional setting: high school classrooms. Although Experiments 3-4 yielded dramatic gains in knowledge and marked attitude changes upon delayed posttesting, their retention periods of about five days may be considered brief—even if the 400-word intervention itself was *ultra*-brief). With a larger intervention including a manipulated set of six critical, germane statistics, assessing further longevity (about five weeks) seemed appropriate and incumbent. Experiment 5 is uncommon in climate change cognition's literature: not only did it involve an intervention, particularly a *science-based, mechanistic* intervention—instead of a vignette, framing, or pseudo-news-article—it also involved a relatively long post-intervention retention interval. Experiment 5's curriculum thus combined (a) the replicated effect of explaining global warming's mechanism and (b) the promising effect of offering representative statistics (similar to prior NDI-infused curricula used more extensively in Experiments 6 and 7; e.g., Ranney et al., 2008) that support understanding global warming's effects and dangers.

Method

Subjects. Students (N = 63) from three chemistry classes at an urban Northern California high-school participated. They likely demographically reflected the U.S. more so than the undergraduates who comprised the bulk of Experiments 1–3's subjects.

Design, Procedure, and Materials. Experiment 5's curriculum alternated between (a) mechanistic global warming explanations related to Experiments 2-4's and (b) cycles of estimation and numerical feedback. A *mechanism-plus* group (n = 33) received the mechanistic curriculum *and* six key global warming statistics. A *mechanism-only* (quasi-control) group (n=30) received the mechanistic intervention—but with six *un*related, non-key statistics instead. Subjects received 15 minutes' mechanistic global warming instruction on one week's Monday, Wednesday, and Friday. Each day began with estimations of two statistics, followed by feedback and then a brief mechanistic element/enhancement. The three elements were (1) a common molecular-level (and molecule-concentration-level) greenhouse effect simulation (PhET; University of Colorado, 2011), (2) a six-slide presentation on global warming's mechanism (based on a subset of Experiments 2-4's 400 words), and (3) a seven-slide mechanistic elaboration in terms of global warming's causes and consequences. After estimating the six critical climate change quantities, mechanism-plus subjects received the true values as feedback. Mechanism-only subjects received six equally-surprising, climate-*un*related, estimation-feedback values (sampled from Ranney et al., 2008). Experiment 5's survey also included a nine-item Environmental Behavioral Intentions (EBI) scale based on the GEB. Everyone completed a pretest, a non-immediate posttest (three days later; N = 63), and a delayed posttest (34 days later; N = 59). (See Supplemental Materials' Appendix S5 and Table S1—and Felipe, 2012—for more detail on Experiment 5's curricula, for which statistics were addressed when and by whom, or for additional results.)

Results and Discussion

We focus here on scientific mechanistic knowledge, global-warming attitudes, and EBI, reporting a minority of many findings from Felipe (2012) and Clark, Ranney, and Felipe (2013). Main predictions were (1) that mechanistic explanations would yet again yield global-warming understanding gains *and* more pro-environmental attitudes, (2) that the key statistics would enhance such effects, and (3) that the effects would be detected five weeks later.

Pretest mechanistic knowledge was virtually zero—consistent with Experiments 1 and 4's non-University results. However, the 45-minute curriculum markedly improved both groups' explanations: they more correctly included basic mechanistic concepts in average scored values (mechanism-plus-statistics group: : $t(32) = 7.02$; $p < .0001$; mechanism-only group: : $t(29) = 6.12$; $p < .0001$; respective means increased from .06 to 1.20 and from .07 to .98 on a 0-4 scale) . The combined groups' three-day-delay EBI posttest gain was also notable ($t(62) = 5.91$, $p < .00001$; from M = 5.7 to M = 6.2 on its 1-9 scale). The effects replicate Experiments 2-4, showing mechanistic information's utility in enhancing one's global warming understanding and "pro-environment" attitudes. Even more importantly, both groups' gains were significant 34 days later (mechanism-plus: $M = +.27$, $t(28) = 5.2$; mechanism-only: $M = +.17$, $t(27) = 3.01$; both p's $< .003$), which seems notable for .005 of a year's course, given the topic's importance and what a more extensive curriculum could offer. (Even though pretest global-warming acceptance for mechanism-plus subjects was near ceiling for the most direct item—8.3 on the 1–9 scale—they significantly gained: $t(32) = 1.76$, $p < .05$.) Crucially, while the mechanism-only group markedly gained through the mechanistic curriculum alone, the mechanism-plus group's mechanistic knowledge retention after 34 days was significantly greater than—roughly double—the mechanism-only group's (+.8 vs. +.3; $t(48.7) = 2.61$, $p < .01$; Felipe, 2012), indicating that the critical statistics reinforced and/or secured the mechanistic information—and perhaps primed learners to more durably encode new knowledge. The differences show separate benefits for mechanistic and statistical information—and show our brief curriculum's classroom suitability. (Some students had trouble understanding global warming as an *extra*, anthropogenic, greenhouse effect—highlighting the importance of grasping climate change's parameters.)

Beyond its curricular success, Experiment 5 exhibited an enhancing role for key, germane statistics. Experiment 6 assesses whether statistics *alone* can boost global warming acceptance, using the Numerically Driven Inferencing (NDI) paradigm (Ranney et al., 2008).

Experiment 6: *Increasing* Global Warming Acceptance with Representative Statistics

With NDI techniques, subjects typically estimate a quantity before learning its true value. (Conditions that have offered the true values without prior estimation have yielded more hindsight bias and/or post-hoc rationalization—reducing statistics' impact; e.g., Rinne, Ranney, & Lurie, 2006.) Given the NDI paradigm's successes and the utility of Experiment 5's mechanism-plus group's numeric feedback, we developed and administered an intervention with field-tested numerical facts to assess the benefit, in isolation, of statistical global warming evidence. In contrast to the “misleading” numbers used in the next/final study (Experiment 7), we call Experiment 6’s statistics “representative” numbers. Based on NDI studies of similarly shocking magnitudes (with “shock” being a technical term involving a single estimate-feedback mismatch; Munnich, Ranney, & Song, 2007; also see Garcia de Osuna, et al., 2004), we hypothesized that representative statistics’ surprising feedback values[13] would increase subjects’ climate change acceptance, yet diminish self-confidence in their climate-change knowledge.

Method

Subjects. Forty MTurk workers were recruited and two were excluded (as per Experiment 4’s criteria), leaving 38 (47% women). Democrats (45%) were slightly overrepresented—typical, as noted above, of MTurk samples. The mean conservativism self-rating was 4.0 ($SD = 2.1$, with all ratings on 1–9 scales)—comparable to that of our experiments with undergraduates.

Design, Procedure, and Materials. Instructional and survey materials paralleled Experiment 4’s, with the central difference that a numeric intervention similar to part of Experiment 5’s—albeit improved, and revised for adults—fully replaced the mechanistic intervention. Subjects estimated each of seven statistical quantities and later received the true values as feedback. Appendix B displays the seven items, including a scientific consensus[14] item. (The Supplemental Materials’ Appendix S6—and Clark, 2013—offer more detail.)

Results and Discussion

Experiment 6’s intervention succeeded (cf. Clark, Ranney & Felipe, 2013’s, Study 3)[15] in significantly increasing global-warming acceptance/concern ratings from pretest to posttest (*M*’s of 6.4 and 6.8—a gain of 15% of the 1–9 scale’s “available room;” $t(37) = 2.74$, $p < .005$). This shows that feedback with as few as seven carefully crafted, critical, germane statistics can shift subjects’ beliefs toward the scientific consensus. (The seven’s mean *surprise* ratings ranged from

3.2 to 6.3.) Notably, the correlation between one's conservativism and one's global-warming acceptance increase was *not* significant and effectively zero (r = -.07, p = .67)—thus indicating *no* polarization. This finding coheres with Experiment 4's *lack* of polarization found regarding the utility of explaining global warming's mechanism. Experiment 6's purely-statistical-feedback results (recently replicated) mean that *two* quite different forms of scientific information—mechanistic or statistical-evidential, incarnated as interventions as above and here—can yield global warming understandings that are more consistent with the scientific consensus without yielding polarization effects (cf. Kahan et al., 2012). As anticipated based on prior NDI studies, these largely surprised subjects reported feeling less knowledgeable, post-feedback (M = 4.2), than pre-feedback (M = 5.2; $t(37) = -3.38$, $p < .001$). When subjects' estimates are distal from the true values, they obviously gain some knowledge—yet they often lose confidence in realizing that their prior competence-assessments were (sometimes wildly) optimistic. This confidence-loss was uncharacteristic of the (prior experiments') *mechanistic explanations'* effects.

Experiment 7: *Decreasing* Global Warming Acceptance with Misleading Statistics

Trying to undercut global warming's reality/gravity, some groups publicize out-of-context or "cherry picked" statistics—such as, that Earth cooled *slightly* by 0.2^{o}F during 1940-1975 (Jastrow, Nierenberg, & Seitz, 1991). The tiny dip—only *.04%* in ^{o}K—is largely explained by global/solar "dimming" due to anomalous increases in anthropogenic aerosols that eventually could no longer mask greenhouse-gas-driven warming by 1975. The datum hardly contradicts the obvious warming trend over the last 130+ years, yet people can be misled with anomalously high and low data-points from noisy time series. (See Lewandowsky, Ecker, Seifert, Schwarz, & Cook's 2012 discussion of tools for correcting such information.) Given their agnotological intent (Oreskes & Conway, 2010), we label such numbers "misleading." Experiment 6 yielded attitude change with *representative* statistics, so Experiment 7's main hypotheses were that a handful of misleading statistics can reduce one's (a) global warming acceptance, (b) climate-change funding preferences, and (c) self-ratings of global warming knowledge.

Method

Subjects. UCB undergraduates (N =104; 39% Democrats) from two courses (Behavioral Change, Cognitive Science) were each randomly bifurcated into conditions.

Design, Procedure, and Materials. Experiment 7's design paralleled Experiment 2's, with the central difference that the mechanistic intervention was replaced with one of two interventions that, like Experiment 6's, involved statistical estimations and feedback values—albeit misleading ones here. A high-time-per-item, "two-item group" (n = 45) experienced only two quantities, with subgroups of about 11 subjects experiencing each of four disjoint item-pairs; these randomly assigned subgroups completed a pretest and extra questions about each item—for instance, we (a) asked about surprise-level after giving each feedback value and (b) elicited both subjects' climate-change funding *policies* and post-feedback policy *changes* regarding/versus various UN (UNDP) goals. (See Supplemental Materials' Appendix S7 for UNDP goals and climate-related funding choices.) The remainder (n = 59) of the subjects was assigned to a low-time-per-item, "eight-item group" that estimated all eight quantities before receiving the feedback values. (Given the misleading nature of these items, we do not provide them here, but we are open to discussions regarding them.) The eight-item group's survey included no policy querying and no pretest—only a posttest. Naturally, we immediately debriefed subjects—with an hour of extensive information and clarification—more than the interventions of Experiments 4 and 6 together; results of a more recent experiment indicate that such debriefings are successful.

Results and Discussion

As predicted, climate change acceptance significantly dropped—from pre- to post-test for the two-item group (*M*'s = 6.5 and 6.2; $t(42) = -4.3$, $p < .0001$)—and dipped further to 5.9 for the eight-item group (dropping about 11% of the available room, $t(88.6) = -2.61$, $p < .005$). As these mean shifts were toward ambivalence (a "5" rating), they seemed to reflect confusion rather than non-acceptance. Indeed. as predicted, self-rated knowledge (a) fell from a 5.0 pretest mean to 4.5 for the two-item group ($t(44) = -2.5$, $p < .01$) and (b) plummeted to 2.9 following all eight items ($t(87.2) = -5.3$, $p < .00001$). This large latter (2.1) decrease, after only eight misleading statistics, was 53% of the *possible* 4.0 self-rated knowledge change. (It also roughly doubled Experiment 6's 1.0 representatively-caused knowledge-confidence decrease.) Yet further predicted, funding preferences for global-warming-related UN goals dropped ($\chi^2(1) = 22$, $p < .01$) versus *all* eight non-climate UNDP funding alternatives. Finally, as in the prior experiments, we observed no polarization; the correlation between conservatism and global-warming acceptance change was virtually zero and actually positive in sign ($r = .009$, $p = .95$)—that is, the liberals numerically reduced their global warming acceptance nonsignificantly *more* than did the conservatives.

Experiment 7 shows that even well-educated people (e.g., undergraduates at a prestigious university) are quite susceptible to misleading, cherry picked facts. Such statistics are used by organizations seeking to undermine public perceptions of the scientific climate–change consensus. Cognitive (and other) scientists, educators, and communicators ought (continue to) counter such increasingly sophisticated distributions of misleading information. Furthermore, unlike with this article's previous UCB studies, Experiment 7 intentionally moved subjects' beliefs *away* from Berkeley students' stereotypically liberal pole—which represents additional evidence against both polarization and the stasis view. Public science education thus seems powerful—albeit dangerous in malicious or avaricious hands (cf. Lewandowsky et al., 2012).

Consumers of information must better detect nonrepresentative aspects, such as those lacking temporal breadth or recency (e.g., "1940-1975" in the statistic above, even though we have data from at least 1850 and obviously past 1975)—or such as those lacking in measurement precision, reasonable spatial extent, and authority (see Oreskes & Conway, 2010).

HowGlobalWarmingWorks.org for Mechanisms and Other Science Information

Experiments 1-5 collectively demonstrated both a dearth of mechanistic global warming knowledge and the utility of explaining that mechanism to enlighten people about climate change's nature and ontology. Therefore, it seemed incumbent to directly disseminate the information to the public, given how rarely even journalists and teachers read technical writings. Ranney, Lamprey, Reinholz et al. (2013) therefore produced five videos—from 52 seconds to 4.7-minutes (83 to 596 words)—that are based on the 400 words and up to 200 more/other words. These videos, along with statistics, graphs, video-transcripts, and other materials, are at www.HowGlobalWarmingWorks.org. Formally announced in mid-December, 2013, this public-service site has yielded many page-views—directly (almost 200,000) and indirectly (roughly 1,000,000, e.g., through journalists and bloggers focally discussing the site's contents).[16] The site also includes, among other aids, (a) Experiments 2-5's 400-word mechanism explanation and its 35-word "Shorter Summary," (b) pages that our laboratory translated into Chinese explaining how to access materials/videos (via China-allowed Youku) with Mandarin audio, Chinese labels and graphics, etc., (c) German videos, (d) descriptions of how to view captioned videos in about 75 other languages (via Google Translate), (e) the representative statistics from Experiment 6, and (f) recently assessed graphs that compellingly illustrate Earth's temperature increase—in similarity to stock-market increases (inspired by Lewandowsky, 2011). FAQ pages are planned.

The website/videos/etc. represent attempts to satisfy three goals: (1) We wish to provide over 7 billion people with terse, accurate, compelling, mechanistic (and other) global warming information that is undiluted or unmutated by (often well-meaning) providers who may be unclear about it; instructors and/or the media often provide flawed material (Ranney et al., 2008)—or they often obscure the scientific mechanism in haystacks of peripheral information about the *effects* of climate change (which is better known, regardless) or with unnecessarily novel/distracting high-cognitive-load terms such as “albedo” or “radiative forcing.” (2) We hope to discern which of the five videos maximally, or most efficiently, increases both understandings of global warming’s mechanism and appropriate epistemic/ontologic positions about global warming (e.g., a justified acceptance of anthropogenic global warming); we are thus now assessing the five videos for resultant knowledge and attitude changes, and Arnold et al. (2014) have already found that our four-minute, 444-word, German video triples mechanistic knowledge and increases global warming acceptance—further disconfirming stasis. (3) We hope that website visitors might contact their local and federal representatives (or rulers) to express themselves about international agreements to impede global warming.[17]

General Discussion

We have replicably demonstrated that a critical aspect of global warming knowledge, regarding its chemical/physical *mechanism*, is virtually nonexistent in the U.S. public (Experiments 1–5),[18] and these findings have essentially been thrice-replicated by Arnold et al. (2014) with German subjects. Fortunately, Experiments 2–5 and Arnold et al.’s (2014) data represent fivefold demonstrations (with retention observed as much as 34 days later) that short explications (e.g., roughly 400 words in Experiments 2-4 and Arnold et al., 2014) dramatically increase such knowledge—*and* that the interventions also increase climate change acceptance and (typically) concern. We further showed that a handful of poignant statistics—whether germane (Experiment 6) or *un*representatively cherry-picked (Experiment 7)—can respectively enhance or erode global warming acceptance. Finally, we introduced a website dedicated to quickly increase public global warming knowledge: www.HowGlobalWarmingWorks.org.

Experiment 1 demonstrated the relationship between mechanistic global warming knowledge and global warming acceptance—the first of our contradictions of "stasis theory," the notion held by some researchers and many laypeople that suggests that climate science information may be largely futile and perhaps even counterproductive. As noted in Experiment 1's Discussion, this finding coheres with 9-10 other studies that link climate change acceptance and knowledge; five of these aforementioned studies show similar results regarding *mechanistic* knowledge in particular—notably Arnold et al.'s (2014) German replications of Experiment 1.

Experiments 2-6's interventions (and Arnold et al., 2014) go further and actually *disconfirm* stasis theory, showing that acquiring mechanistic or statistical knowledge can increase global warming acceptance; indeed, even Experiment 7 shows that true (albeit misleading) information can change attitudes, further disconfirming stasis theory. Experiments 4, 6, and 7 yet further disconfirm stasis theory in that they evidenced no polarization-suggesting correlation between conservatism and induced changes in global warming acceptance. Changing global warming beliefs is hardly easy, and our successful interventions came from much effort. However, beyond the mounting weight of evidence disconfirming it, stasis theory (a) is historically naïve (as elaborated above), (b) suffers from range restrictions[19], and (c) is advocated, in part, by some researchers who misinterpret (and/or understate) knowledge-attitude correlation[20] data and the rare climate-change-involving bits of polarization data (cf. Kahan et al., 2012).[21] In contrast to the correlational aspect, our data are virtually always obtained in controlled experiments—a gold standard regarding causal inference—and we have found *no* evidence of polarization in *any* of our studies. (Fernbach, Rogers, Fox, & Sloman, 2013, similarly find that *mechanistic* explaining—which our subjects did in Experiments 1-5—inhibits polarization.)

Few scholars in general have assessed *mechanistic* global warming knowledge, and even fewer have experimentally increased it—let alone also increased global warming acceptance; Experiments 1-5 (and Arnold et al., 2014) collectively accomplished all of these, and Experiments 6 and 7 further illustrated climate information's (e.g., statistics') belief-revising power. These counter-stasis findings cohere with McCright et al.'s (this issue) that show that even prose with little science information (i.e., non-mechanistic frames about economic opportunity or national security) increases attitudes toward the positive effects of governmental greenhouse gas reductions, and even in the face of "denial counter-frames." Given that there is no reasonable scientific counter-mechanism to the explanation embodied in our 400 (or even 35) words, we predict that it may prove more robust to counter-frames than frames themselves; one ought not conclude from Experiments 6-7's persuasiveness that statistics, particularly Experiment 7's, would nullify the tie-breaking effect of a coherent, broad, mechanistic explanation. Likewise, other interventions (e.g., by Sinatra and colleagues; see Lombardi, Sinatra, & Nussbaum, 2013) can disconfirm the stasis view and durably increase climate change acceptance.

Results Summary: Practical Changes in Knowledge, Beliefs, and Attitudes

Readers are likely interested in practical gains beyond statistical significance, which seem best discussed regarding the "remaining room to 100% knowledge/agreement" (should unanimity be desired; cf. that all people ought understand and accept gravity). Regarding *knowledge*, subjects' initial mechanistic global warming understandings all started low (albeit varying by subpopulation), For Experiments 1-5, respective mean *proportions* of pre-instruction full-credit knowledge were: .22 (San Diego denizens), .26 (Berkeley [.33] and Brownsville [.11] undergraduates), .42 (Berkeley undergraduates), .21 (MTurk subjects), and .02 (high school students). However, Experiments 2-5 yielded substantial global-warming understanding increases following their brief mechanistic interventions, which—in terms of the *possible* gain from pretest understanding to the scales' extremes—were respectively: +41%, (Berkeley [+54%] and Brownsville [+28%]), +52% (Berkeley undergraduates), +41% (MTurk participants), and +26% (high school students). *Delayed* post-test knowledge gains—again, with respect to *possible* gains—for Experiments 3-5 were respectively (also respectively after 4, 5.5, and 34 days): +48%, +28%, and +14% (with 20% for Experiment 5's mechanism-plus condition).

Regarding global-warming *acceptance*, Experiments 2-6 yielded increases following their brief interventions, which—in terms of the possible gain from pretest to extreme agreement—were respectively (with mechanistic information:) +14%, +12%, +11%, and (after a three-day delay:) +15%—as well as (with just representative statistics:) +15%; the latter finding using representative statistics has been replicated with a new experiment that has yielded an even larger acceptance gain of 20% (maintained after nine days). (Experiment 7's misleading-statistics acceptance change was -11% of the "available room"—i.e., toward extreme *dis*agreement—and this effect has also been replicated in a new experiment.) *Delayed* posttest attitude increases for Experiments 3-5's mechanistic interventions—again, with respect to possible increases—were respectively (following respectively after 4, 5.5, and 34 days): +9%, +11%, and +6%.

In sum, Experiments 2-5's brief interventions yielded a median effect of 41% of the possible knowledge gain—and 28% upon delayed post-testing. The median immediate acceptance-gain effect among Experiments 2-6 was 14% of the possible gain, and that median acceptance-gain effect after 4-to-34-day *delays* was 9% of what was possible. As to the practical significance of the acceptance changes, one might imagine the policy changes possible, given how close many elections are, if all people experienced such brief interventions (a goal of HowGlobalWarmingWorks.org)—let alone if they experienced (1) longer interventions, (2) reminders of the interventions' contents, and/or (3) *combinations* of the interventions discussed above (e.g., from Experiments 4 and 6, as well as information/videos from HowGlobalWarmingWorks.org)—along with interventions using the aforementioned graphs that compellingly illustrate Earth's 130+ years of temperature data (or even newly assessed statistics that work indirectly by reducing Americans' U.S.-provincialism).

Conclusion

Global warming is perhaps humankind's greatest threat, and would-be researchers might fear studying climate change cognition for various reasons. (However, contrary to what those who deny global warming may claim, not only do scientists overwhelmingly wish it were not occurring—they would self-interestedly leap at even a small chance to disconfirm it; Edx.org/understanding-climate-denial, 2015.) But there are tremendous grounds for *optimism*: Fortunately, analyses collectively suggest that people already have sustainable technologies inexpensive enough for us to quickly adopt them for much less than the five trillion annual post-tax dollars (6.5% of global GDP; Coady, Parry, Sears, & Shang, 2015) that humans currently bear subsidizing fossil fuels—thus markedly retarding the current global warming and saving funds in the long term, should the planet garner requisite political will (cf. Harte & Harte, 2008). Also fortunately, we show above that global warming's basic mechanism can be captured in just 35 words; it would likely take many more words to mechanistically explain most other “contested” science realms such as evolution or vaccines. On the empirical side, 81% of Americans, including 71% of Republicans, already believe that climate change is at least partly anthropogenic (an increase of about 9% since 2011; Davenport & Connelly, 2015)—among other indicators of increasing public climate acumen (e.g., that 77% of Americans want the government to substantially combat climate change). Furthermore, our experiments—beyond the knowledge gains demonstrated—show that, with apparently *zero* polarization (cf. Kahan et al., 2012), we can quickly cause more people to (1) accept global warming’s reality (as climatologists see it), (2) express concern about it, and (3) orient toward action regarding it. Naturally, *intentions* to act are not *actions*, but they are often actions’ precursors.

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Appendix A: 400-Word Text Explaining the Mechanism of Global Warming

(Experiments 2-4; from Ranney et al., 2012b)

How does climate change ("global warming") work? The mechanism of the greenhouse effect

[Or: "Why do some gases concern scientists—like carbon dioxide (CO2)—but not others, like oxygen"]

Scientists tell us that human activities are changing Earth's atmosphere and increasing Earth's average temperature. What causes these climate changes?

First, let's understand Earth's "normal" temperature: When Earth absorbs sunlight, which is mostly visible light, it heats up. Like the sun, Earth emits energy—but because it is cooler than the sun, Earth emits lower-energy infrared wavelengths. Greenhouse gases in the atmosphere (methane, carbon dioxide, etc.) let visible light pass through, but absorb infrared light—causing the atmosphere to heat up. The warmer atmosphere emits more infrared light, which tends to be re-absorbed—perhaps many times—before the energy eventually returns to space. The extra time this energy hangs around has helped keep Earth warm enough to support life as we know it. (In contrast, the moon has no atmosphere, and it is colder than Earth, on average.)

Since the industrial age began around the year 1750, atmospheric carbon dioxide has increased by 40% and methane has increased by 150%. Such increases cause *extra* infrared light absorption, further heating Earth above its typical temperature range (even as energy from the sun stays basically the same). In other words, energy that gets to Earth has an even *harder* time leaving it, causing Earth's average temperature to increase—producing global climate change.

[In molecular detail, greenhouse gases absorb infrared light because their molecules can vibrate to produce asymmetric distributions of electric charge, which match the energy levels of various infrared wavelengths. In contrast, non-greenhouse gases (such as oxygen and nitrogen—that is, O2 and N2) don't absorb infrared light, because they have symmetric charge distributions even when vibrating.]

Summary: (a) Earth absorbs most of the sunlight it receives; (b) Earth then emits the absorbed light's energy as infrared light; (c) greenhouse gases absorb a lot of the infrared light before it can leave our atmosphere; (d) being absorbed slows the rate at which energy escapes to space; and (e) the slower passage of energy heats up the atmosphere, water, and ground. By increasing the amount of greenhouse gases in the atmosphere, humans are increasing the atmosphere's absorption of infrared light, thereby warming Earth and disrupting global climate patterns.

Shorter summary: Earth transforms sunlight's visible light energy into infrared light energy, which leaves Earth slowly because it is absorbed by greenhouse gases. When people produce greenhouse gases, energy leaves Earth even more slowly—raising Earth's temperature.

Appendix B: Experiment 6's Information as Seven Representative Statistics/Numbers

Textual description	**Format / *Correct Value***
Global surface temperatures have been recorded since 1850. According to the 2007 report from the Intergovernmental Panel on Climate Change, how many of the years between 1995-2006 (a 12 year period) are one of the hottest 12 years recorded?*	"# of years" / *11 years*
What is the change in the atmospheric levels of methane (a greenhouse gas) since 1750?*	"% increase" or "% decrease"/ *151% increase*
What is the change in percentage of the world's ocean ice cover since the 1960s?*	"% increase" or "% decrease" / *40% decrease*
According to observation data collected at Mauna Loa Observatory in Hawaii, what is the percent change in atmospheric CO2 levels from 1959 (when observation began) to 2009?*	"% increase" or "% decrease" / *22.6% increase*
A 2010 article examines the 908 active researchers with at least 20 climate publications on Google Scholar. What percentage of them have stated that it is "very likely" that human-caused emissions are responsible for "most" of the "unequivocal" warming of the Earth in the second half of the 20th century?	"% of researchers" / *97.5%*
In 1850 there were approximately 150 glaciers present in Glacier National Park. How many are present today?	"# of glaciers"/ *25 glaciers*
From 1850 to 2004, what is the percent change of volume of glaciers in the European Alps?	"% increase" or "% decrease" / *50% decrease*

* = These four items were also among the six items used in Experiment 5's mechanism-plus group; see Table S1 in Appendix S5 of the Supplementary Materials.

Author Note

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This article contains information that appears here alone, but Experiments 1-7 are described elsewhere, often with more available descriptive space. Therefore, for additional (usually more) explicit information about motivations, methods, and findings, please note that Experiment 1 appears in Ranney et al. (2012a, Study 1) and in considerable detail in Cohen (2012); Experiment 2 appears in Ranney et al. (2012a; Study 2) and also in Clark (2013; Study 6.1); Experiments 3, 5, and 7 appear in Clark, Ranney, and Felipe (2013; Studies 1, 4, and 2, respectively); Experiments 3 and 7 also appear with considerable detail in Clark (2013; Studies 6.2 and 4.2); Experiment 5 also appears with considerable detail in Felipe (2012); Experiments 4 and 6 appear with considerable detail in Clark (2013; Studies 6.3 and 5.2). Given present allotted space, we have generally compacted the studies here, but we have more richly explicated a minority of the studies.

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Footnotes

[1] We herein strive to consistently distinguish “global warming,” meaning Earth’s mean (surface/ocean) temperature rise, from “climate change,” which naturally implies that not each of Earth’s cubic kilometers will become monotonically hotter during the current warming.

[2] As described herein, Experiment 1 is technically a survey. However, for aiding reference, for avoiding confusion regarding this article’s elements versus others (e.g., Clark, Ranney, & Felipe, 2013; Ranney et al., 2012a), and for labeling simplicity regarding the six succeeding experiments, we call it “Experiment 1” throughout.

[3] Reasoning to extremes falsifies the nature-nurture dichotomy: Einstein’s clone would hardly manifest his genius-*nature* if raised in a stimuli-depriving box; likewise, a severely brain-damaged person will not master quantum mechanics merely by even superb tutors’ *nurture*.

[4] When pressed, culture-only champions rarely assert a 0.00% chance for information to change attitudes—but near-0% assertions are so common that we address them as an archetype.

[5] One’s “cultural/political” bias appears anti-empirical, and overly top-down: Joining a political party or other “clan” often reduces disconfirmatory information-gathering attempts—whereas scientists, ideally, are *rewarded* for disconfirming cherished theories.

[6] Relevant to global warming acceptance’s culture-science synergy, all 15 of RTMD theory’s (e.g., Ranney, 2012) predictions were directionally supported—replicating prior findings (with 13 statistically significant; p’s < .01; Ranney et al., 2012a). Likewise, evolution/creation acceptance—even more so than political party—again strongly predicted global warming knowledge and acceptance (as both occurring *and* anthropogenic). Most of Experiments 2-7 also included RTMD items/measures, but they are not reported herein.

[7] Guy et al. (2014) suggest that controlling for important covariates may have yielded different results for Kahan et al. (2012).

[8] Scientific literacy, which we hope to increase in the public, includes seeking causal explanations; indeed, as noted below, people who deny global warming ought to explain how, causally, massive anthropogenic greenhouse gas emissions could be relatively inert.

[9] Surprise-ratings differences between the pretest-and-posttest and no-pretest groups further supported the idea that pre-information explanation/theory elicitations *increase* surprise—and *reduce* post hoc rationalization/ hindsight (Clark & Ranney, 2010; Munnich, Ranney, & Song, 2007; cf. Rinne, Ranney, & Lurie, 2006, whose PEIC procedure is partly used in Expts. 5-7).

[10] Unless otherwise noted, all t-tests are one-tailed, as our hypotheses were clearly directional; when relevant, though, variance between groups was not assumed to be equal.

[11] The pretest-to-posttest gain represents 12.1% of the possible attitude-increase—excellent for a brief, online, intervention: an average reader reads 400 words in about 1.5 minutes.

[12] We use "polarization" in a high-threshold sense (akin to Lord et al., 1979): it occurs when provided-information that would change a neutral person's position in one direction causes a biased person to change in the *opposite* direction. Many use "polarization" more weakly—such as that liberals and conservatives (a) differ on an issue or (b) are differentially changed, albeit in the same direction.

[13] Ranney and Ryunosuke Fujinomaki have found that even subjects from Fukushima, Japan (N = 93) underestimate how dire each of Appendix B's statistics are—consistent with the well-documented knowledge gap between climatologists and laypeople.

[14] Many communicators (e.g., Lewandowsky et al., 2013; Maibach et al., 2013), justifiably find consensus information critical.

[15] An initially conducted experiment (Study 3 in Clark, Ranney & Felipe, 2013) with UCB undergraduates detected neither hypothesized changes, but we improved the method to conduct Experiment 6. See Clark (2013, Chapter 5) for (a) that experiment's details, (b) some conjectures regarding its null results, and (c) some reasons why Experiment 6 proved more successful.

[16] The site's announcement co-occurred with a famous U.S. "polar vortex," likely inhibiting early page-view growth.

[17] With Matthew Shonman, Lee Nevo Lamprey, and Liam Gan, we are also analyzing our website's visitor-comments—and comments posted to websites that address our website/videos.

[18] These results cohere with Fernbach et al., 2013's; they found that mechanistic explanations about various topics help undermine false perceptions of one's understanding.

[19] As we repeatedly showed, public *mechanistic* global warming knowledge is virtually nil. So, *coarse* knowledge measures (e.g., education, self-reported knowledge, or general science knowledge) yield inconsistent associations with climate change acceptance in the literature.

[20] Stasis theorists have conducted a few experiments involving climate change elements (e.g., Kahan, 2013a; most relevantly: Kahan, Jenkins-Smith, & Braman, 2011; Kahan et al., 2015), but seemingly *none* that assess or introduce significant mechanistic knowledge.

[21] Stasis theorists seem of inconsistent commitment. For instance, Kahan et al. (2015) acknowledge an information channel, and even report that subjects receiving geoengineering information increased their climate change concern. Similarly, Kahan et al. (2011, p. 169) thrice acknowledge the potential deliberative role for scientific information/content/evidence. Indeed, Kahan was quoted saying (Simons, 2013, p. 157), "But people do manage to converge on what's known, collectively, somehow. The only way they can do it is by figuring out who knows what about what. You don't have to have a medical degree to know to go to the doctor."

Supplemental Materials (Appendices S1 to S7)

for Ranney & Clark's article in *Topics in Cognitive Science* entitled:

"Climate change conceptual change: Scientific information can transform attitudes"

Appendix S1: *Experiment 1's Survey Items*

How much *effort* do you think the *federal* government should put into addressing the issues below?

(please circle your response)	A lot less	Moderately less	About the same	Moderately more	A lot more
Maintaining drinkable water	1	2	3	4	5
Reducing pollution in the nation's rivers and lakes	1	2	3	4	5
Developing open space (e.g., for housing or businesses)	1	2	3	4	5
Creating international treaties to limit greenhouse gas emissions worldwide	1	2	3	4	5
Reducing the loss of tropical rainforests	1	2	3	4	5
Creating alternative energy programs (e.g., solar or wind power)	1	2	3	4	5
Reducing America's greenhouse gas emissions	1	2	3	4	5
Developing "green" technology	1	2	3	4	5
Creating "green" job programs	1	2	3	4	5
Protecting the ozone layer	1	2	3	4	5
Maintaining economic growth (even at the expense of the environment)	1	2	3	4	5
Reducing air pollution in the U.S. (e.g., acid rain)	1	2	3	4	5
Protecting plant and animal species from extinction	1	2	3	4	5
Lowering government regulation on greenhouse gas emissions	1	2	3	4	5
Creating more public transportation	1	2	3	4	5
Encouraging the use of fertilizers to improve agricultural production	1	2	3	4	5
Creating more protected coastal areas	1	2	3	4	5
Taxing gasoline	1	2	3	4	5
Managing urban air pollution (e.g., smog)	1	2	3	4	5
Creating more nuclear power plants	1	2	3	4	5

Please circle whether you agree or disagree with the following statements:

1) I am certain that global warming (i.e., climate change) is actually occurring.

1	2	3	4	5
Strongly Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Strongly Agree

2) Human activities are a significant cause of global warming.

1	2	3	4	5
Strongly Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Strongly Agree

Please answer the following questions in about 3 sentences: (If unsure, please guess or write "I don't know.")

3) Regardless of whether *you* believe that global warming is occurring, what do scientists (who think that global warming is occurring) believe causes global warming?

4) How is global warming supposed to work (according to scientists who think that global warming is occurring)? That is, what is the basic physical, chemical, or biological mechanism of global warming?

5) What can be done to slow global warming, according to those who believe that it is occurring?

6) How are humans, if at all, believed to contribute to global warming?

7) What distinguishes a greenhouse gas from other types of gases in our atmosphere?

6) What is an example of a greenhouse gas? ______________

Please rate whether the following actions cause global warming:	Not a cause	Minor cause	Major cause
Emissions from industry or business	1	2	3
Use of chemical pesticides	1	2	3
Combustion of oil	1	2	3
Using aerosol spray cans	1	2	3
Using residential heating or cooling	1	2	3
Use of chemical fertilizers	1	2	3
Combustion of coal	1	2	3
Deforestation	1	2	3
Emissions from livestock	1	2	3
The generation of power in nuclear power plants	1	2	3
Use of air transportation	1	2	3
Depletion of the ozone layer in the upper atmosphere	1	2	3
Driving gasoline-powered cars	1	2	3

Please rate your opinions about the following hypothetical scenarios:	Definitely vote against	Probably vote against	Undecided	Probably vote for	Definitely vote for
Would you vote for a policy that *dramatically* reduced greenhouse gas (GHG) emissions AND increased the income tax rate for all Americans by **1%**?	1	2	3	4	5
Would you vote for a policy that *dramatically* reduced GHG emissions AND doubled the price of gas?	1	2	3	4	5
Would you vote for a policy that *dramatically* reduced GHG emissions AND caused the U.S. to decline in relative economic power among the world's countries?	1	2	3	4	5
Would you vote for a policy that *dramatically* reduced GHG emissions AND caused *sales taxes* in California to increase across the board by **1%**?	1	2	3	4	5

Please specify your political party affiliation:

1. None	4. Independent	7. Other (please specify): _________
2. Democrat	5. Libertarian	8. Decline to state
3. Green	6. Republican	

Please specify your highest educational level:

1. No high school diploma	5. Bachelor's Degree
2. High school diploma	6. Master's Degree
3. Some college, no degree	7. Professional Degree
4. Associate's Degree	8. Doctorate

Please specify your gender: **M** or **F** **Please specify the zip code in which you live**: _________

Are you an American citizen? Yes or **No**

If not an American citizen, how many years have you resided in the United States? _________

Please specify your age in years: _________

Do you have children or are planning to have children (please circle response)? (Yes / No / Undecided)

What is your main religious faith, if you had to pick one?

1. Atheist	5. Hindu	9. Other (please specify): _________
2. Agnostic	6. Jewish	10. Decline to state
3. Buddhist	7. Muslim	
4. Christian	8. Spiritual but not religious	

Appendix S2: *Pencil-and-Paper Version of the Mechanism Intervention*

Below is a faithful reproduction of the core intervention given to individuals in Experiment 2's pretest-and-posttest condition. This condition, and the experiment's no=pretest condition included page numbers (omitted here to avoid confusion with Supplemental Materials page numbers). The no-pretest survey included a brief set of exploratory open-ended questions (partly to even up time between the conditions) that are not included here.

The online version (for Experiments 3 and 4) was quite similar, with largely identical instructions—the primary difference being the addition of some provisions for quitting the experiment by closing the browser. In addition, the online survey items were randomized, and a few more were added.

Please read now: General Instructions

Intimately related to today's lecture, you are asked to take part in an informative 15-minute study. Thank you for your participation! We believe that you will find this interesting, and we hope that it will also result in some good for society.

The survey looks longer than it is. Some pages have only one item on them.

Associated with this survey is a consent form. If you will, please read it and sign it now. We will collect it soon, and you will be offered a copy of it later.

Once we begin, you may also ask a question at any time. (Pilot-testing suggests that the survey is rather clear, but one never knows!)

This study involves NO deceptions. There is NO "trick" involved, and what we are asking about is what we are actually interested in. Further, any information that we provide you is accurate; for instance, you can share the information with your family tonight, if you wish.

Please *don't* look at your neighbors' surveys. We are using multiple versions, and it will confuse you/us if you have straying eyes. Also, please don't skip ahead and don't go back to an earlier page.

For items that use a 1-9 scale, please respond to them by indicating the degree appropriate—for instance, by circling a number on the 1 to 9 scales below (1 for the least/lowest and 9 for the most/highest).

Please answer honestly regarding your true thoughts and beliefs. We underlined words that might be easy to misread like "not" and "don't," but please be sure to read each item carefully.

We have a limited time to administer this survey, so please answer the short-answer items with some brevity. Note that some items only ask you if you would "add anything" to what you wrote on a page that is only 1-2 pages back. On these items, there is no need to repeat what you wrote those 1-2 pages back. Add what you will, and if you have nothing to add, simply indicate that and move onto the next item.

Again, your participation is sincerely appreciated—and for a good cause. You will receive feedback regarding what this research is for during the lecture, and you can ask anything you wish at that time.

Do you have any questions?

Thanks again!

Please respond to the following items, if you will, with a brief textual answer. Items are on separate pages to prevent backtracking, and it is expected that you will leave a large amount of empty space on these pages.

Please write 1-3 sentences (about **30** words or less) that you could use to explain how climate change occurs to a senior in high school:

Please go on to the next page. At that point, please do not return to this page.

On the previous page, you responded to the following request:

"Please write 1-3 sentences (about 30 words or less) that you could use to explain how climate change occurs to a senior in high school."

*Briefly (**25** words or less), what would you add, if anything, in response to the following?*

Please explain any differences regarding how energy (i.e., heat, light) travels to the Earth from the sun compared to how energy travels away from the Earth:

Please go on to the next page. At that point, please do not return to this page.

On the previous pages, you responded to the following requests:

1) "Please write 1-3 sentences (about 30 words or less) that you could use to explain how climate change occurs to a senior in high school."

2) "Please explain any differences regarding how energy (i.e., heat, light) travels to the Earth from the sun compared to how energy travels away from the Earth."

*Briefly (**25** words or less), what would you add, if anything, in response to the following questions?:*

Are all gases "greenhouse gases?" If not, what makes something a greenhouse gas?

Please go on to the next page. At that point, please do not return to this page.

Please indicate the degree to which you are knowledgeable about climate change—by circling a number on the 1 (not knowledgeable at all) to 9 (extremely knowledgeable) scale below.

1	2	3	4	5	6	7	8	9
Not knowledge-able at all about Climate Change				Moderately knowledge-able about Climate Change				Extremely knowledge-able about Climate Change

Please go on to the next page. At that point, <u>please do not return to this page</u>.

Please respond to the following items, if you will, by indicating the degree to which you agree with each statement—by circling a number on the 1 (extremely disagree) to 9 (extremely agree) scale below.

Evolution accurately explains how plants, animals, and humans came to be as they are.

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

Human activities are largely responsible for the climate change (global warming) that is going on now.

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

The United States is one of the very best countries on our planet (e.g., “in the top three”).

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

There exists a supernatural being/deity (e.g., God) or set of beings/deities (gods).

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

After a person dies, that person experiences an afterlife of some sort (for instance, heaven/hell, reincarnation, enlightenment, nirvana, etc.).

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

Biblical creation accurately explains how plants, animals, and humans came to be as they are.

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

Please go on to the next page. At that point, please do not return to this page.

Global warming or climate changes, when they happen at all, are just parts of a natural cycle.

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

I am certain that global warming is actually occurring.

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

I am worried about global warming.

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

Humans are severely abusing the environment.

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

Evolution is unable to explain much of the physical evidence regarding the origins and development of life on Earth.

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

Other living things may have evolved, but humans have not.

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

Please note the change in wording of the following scale

Overall, how important is it to change your current lifestyle to reduce your carbon footprint (i.e., to decrease the amount of greenhouse gases you emit both directly and indirectly)?

1	2	3	4	5	6	7	8	9
Not Important		Slightly Important		Somewhat Important		Very Important		Extremely Important

Please go on to the next page. At that point, please do not return to this page.

Important! Please read and understand this page.

How does climate change ("global warming") work? The mechanism of the greenhouse effect

[Or: "Why do some gases concern scientists—like carbon dioxide (CO_2)—but not others, like oxygen?"]

Scientists tell us that human activities are changing Earth's atmosphere and increasing Earth's average temperature. What causes these climate changes?

First, let's understand Earth's "normal" temperature: When Earth absorbs sunlight, which is mostly visible light, it heats up. Like the sun, Earth emits energy—but because it is cooler than the sun, Earth emits lower-energy infrared wavelengths. Greenhouse gases in the atmosphere (methane, carbon dioxide, etc.) let visible light pass through, but absorb infrared light—causing the atmosphere to heat up. The warmer atmosphere emits more infrared light, which tends to be re-absorbed—perhaps many times—before the energy eventually returns to space. The extra time this energy hangs around has helped keep Earth warm enough to support life as we know it. (In contrast, the moon has no atmosphere, and it is colder than Earth, on average.)

Since the industrial age began around the year 1750, atmospheric carbon dioxide has increased by 40% and methane has increased by 150%. Such increases cause *extra* infrared light absorption, further heating Earth above its typical temperature range (even as energy from the sun stays basically the same). In other words, energy that gets to Earth has an even *harder* time leaving it, causing Earth's average temperature to increase—producing global climate change.

[In molecular detail, greenhouse gases absorb infrared light because their molecules can vibrate to produce asymmetric distributions of electric charge, which match the energy levels of various infrared wavelengths. In contrast, non-greenhouse gases (such as oxygen and nitrogen—that is, O_2 and N_2) don't absorb infrared light, because they have symmetric charge distributions even when vibrating.]

Summary: (a) Earth absorbs most of the sunlight it receives; (b) Earth then emits the absorbed light's energy as infrared light; (c) greenhouse gases absorb a lot of the infrared light before it can leave our atmosphere; (d) being absorbed slows the rate at which energy escapes to space; and (e) the slower passage of energy heats up the atmosphere, water, and ground. By increasing the amount of greenhouse gases in the atmosphere, humans are increasing the atmosphere's absorption of infrared light, thereby warming Earth and disrupting global climate patterns.

Shorter summary: Earth transforms sunlight's visible light energy into infrared light energy, which leaves Earth slowly because it is absorbed by greenhouse gases. When people produce greenhouse gases, energy leaves Earth even more slowly—raising Earth's temperature.

Please go on to the next page. At that point, please do not return to this page.

Did you find anything in this explanation surprising? Please rate according to the following scale:

1	2	3	4	5	6	7	8	9
Not Surprising At all				Somewhat Surprising				Extremely Surprising

Briefly, what specifically did you find surprising (if anything)?

Please go on to the next page. At that point, please do not return to this page.

Please respond to the following items, if you will, with a brief textual answer. Questions are on separate pages to prevent backtracking, and it is expected that you will leave a large amount of empty space on these pages.

Please write 1-3 sentences (about **30** words or less) that you could use to explain how climate change occurs to a senior in high school:

Please go on to the next page. At that point, please do not return to this page.

On the previous page, you responded to the following request:

"Please write 1-3 sentences (about 30 words or less) that you could use to explain how climate change occurs to a senior in high school."

*Briefly (**25** words or less), what would you add, if anything, in response to the following?*

Please explain any differences regarding how energy (i.e., heat, light) travels to the Earth from the sun compared to how energy travels away from the Earth:

Please go on to the next page. At that point, please do not return to this page.

On the previous pages, you responded to the following requests:

1) "Please write 1-3 sentences (about 30 words or less) that you could use to explain how climate change occurs to a senior in high school."

2) "Please explain any differences regarding how energy (i.e., heat, light) travels to the Earth from the sun compared to how energy travels away from the Earth."

*Briefly (**25** words or less), what would you <u>add</u>, <u>if anything</u>, in response to the following questions?:*

Are all gases "greenhouse gases?" If not, what makes something a greenhouse gas?

Please go on to the next page. At that point, <u>please do not return to this page</u>.

The sun mostly emits ____________ light towards the Earth.

The Earth mostly emits ____________ light out into space.

Please go on to the next page. At that point, please do not return to this page.

Please indicate the degree to which you are knowledgeable about climate change—by circling a number on the 1 (not knowledgeable at all) to 9 (extremely knowledgeable) scale below.

1	2	3	4	5	6	7	8	9
Not knowledge-able at all about Climate Change				Moderately knowledge-able about Climate Change				Extremely knowledge-able about Climate Change

Please go on to the next page. At that point, please do not return to this page.

Evolution accurately explains how plants, animals, and humans came to be as they are.

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

Human activities are largely responsible for the climate change (global warming) that is going on now.

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

The United States is one of the very best countries on our planet (e.g., "in the top three").

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

There exists a supernatural being/deity (e.g., God) or set of beings/deities (gods).

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

After a person dies, that person experiences an afterlife of some sort (for instance, heaven/hell, reincarnation, enlightenment, nirvana, etc.).

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

Biblical creation accurately explains how plants, animals, and humans came to be as they are.

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

Please go on to the next page. At that point, please do not return to this page.

Global warming or climate changes, when they happen at all, are just parts of a natural cycle.

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

I am certain that global warming is actually occurring.

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

I am worried about global warming.

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

Humans are severely abusing the environment.

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

Evolution is unable to explain much of the physical evidence regarding the origins and development of life on Earth.

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

Other living things may have evolved, but humans have not.

1	2	3	4	5	6	7	8	9
Extremely Disagree	Strongly Disagree	Disagree	Mildly Disagree	Neither Agree Nor Disagree	Mildly Agree	Agree	Strongly Agree	Extremely Agree

Please note the change in wording of the following scale

Overall, how important is it to change your current lifestyle to reduce your carbon footprint (i.e., to decrease the amount of greenhouse gases you emit both directly and indirectly)?

1	2	3	4	5	6	7	8	9
Not Important		Slightly Important		Somewhat Important		Very Important		Extremely Important

Please go on to the next page. At that point, please do not return to this page.

Please circle, as appropriate, regarding your background

What is your gender? M/F

Are you a U.S. citizen or permanent resident? Y/N

Were you born in the US? Y/N

If not, how many years have you been living in the U.S? __________

Is English your first language? Y/N

What is your strongest political party affiliation?

1. None
2. Democrat
3. Green
4. Independent
5. Libertarian
6. Republican
7. Other
8. Decline to state

On the following scale, indicate the extent to which you consider yourself to be liberal or conservative on most political and social issues:

1	2	3	4	5	6	7	8	9
Extremely Liberal		Somewhat Liberal		Moderate		Somewhat Conserv-ative		Extremely Conserv-ative

What is your main religious faith?

1. Atheist
2. Agnostic
3. Buddhist
4. Christian
5. Hindu
6. Jewish
7. Muslim
8. Spiritual but not religious
9. Other
10. Decline to state

Thank you. When finished, please turn this survey face down on your desk at this time.

Appendix S3: *Mechanism Items and Coding Scheme for Responses*

Development of the coding scheme was a multi-step process. Initially, members of our research team sought to identify conceptions that occurred across multiple surveys. These conceptions were assigned numerical codes, and these codes were arranged into general categories. Following this, we developed a more complete progression, describing relationships between the various categories, as well as grouping them into "misconceptions," "ignorance," and "mechanistic description." This allowed the beginnings of a scoring rubric to be developed. We then iterated the process with a larger group of coders to arrive at the final product reproduced below. What follows is the full text of the coding packet, which also contains the text for the mechanism questions we asked in our interventions. Given the centrality of these questions, we produce them here as well:

1. Please write 1-3 sentences (about 30 words or less) that you could use to explain how climate change occurs to a senior in high school.

2. Please explain any differences regarding how energy (i.e., heat, light) travels to the Earth from the sun compared to how energy travels away from the Earth.

3. Are all gases "greenhouse gases?" If not, what makes something a greenhouse gas?

Note that S. Cohen (2012) also reported a coding scheme (available upon request), though that scheme exhibits differences with the one described here. A diagram (see Clark, 2013, for this and further details) representing relationships among the codes was also provided to coders. A section containing a set of notes follow the codes; they provide a set of criteria for choosing between notes, and were used by the final set of coders.

Instructions

1. Responses can be classified in three categories at most. Give them as many codes as possible.
2. If the respondent talks about the differentiation of energy, refer to the "definition of differentiation of energy" table for additional help in categorizing.
3. If the respondent talks about *how greenhouse gases work*, refer to the "definition of greenhouse gases" table for additional help in categorizing.
4. If the respondent mentions greenhouse gases, refer to the "says/mentions greenhouse gases" table for additional help in categorizing.
5. If the respondent talks about *any type of mechanism for climate change*, refer to the "mechanism of climate change table." This table is broken into the sub-categories of energy, source, general chemical reactions, and respondent confusion. Please note that sometimes *a response can fit into more than one subcategory* under the overarching mechanism category.
6. If the respondent leaves a question blank, writes "do not know," or "same as above," refer to the last table, "Don't Know."
7. If the response prompts categorization ambiguities, first look at the response as a whole to look for phrases that might provide a clearer indication of what they mean. If the ambiguity can be clarified without coder inferences or assumptions, categorize the response into the code that provides the most possible credit (i.e., "be charitable within reason"). If the coder cannot clear up the ambiguity or must make assumptions, code the response into the category which best describes what the respondent actually says and not what the coder might think they are trying to say (i.e., "don't infer extra credit"). Also, note whether the respondent is defining something, explaining how climate change works, or *both*. To be doing both, the ideas must be clearly a definition and a mechanism. For instance, to say "greenhouse gases do X and thus trap heat on earth" would be both a definition and a mechanism. Even if a definition is embedded in a phrase that describes the mechanism, give them credit for both the mechanism and the definition.
8. Unless otherwise noted, all the categories listed can be applied to Know_1, Know_2, or Know_3.
9. See example column for examples of each code. Please note that for each example, the response may have been coded into more categories than just the category in which the example is placed (e.g., the example for MCCS2 was coded into SGHG1 as well as MCCS2).

Definition of Terms

Know_1: Please write 1-3 sentences (about 30 words or less) that you could use to explain how climate change occurs to a senior in high school.

Know_2: Please explain any differences regarding how energy (i.e., heat, light) travels to the Earth from the sun compared to how energy travels away from the Earth.

Know_3: Are all gases "greenhouse gases?" If not, what makes something a greenhouse gas?

Categories (Listed) – Please see tables for cutoffs, discussions, and comparisons between categories.

DD: Definition of the Differentiation of Light/Energy

DD1: Respondent differentiates between visible sunlight entering the atmosphere and infrared radiation/heat being emitted by the Earth.

DD2: Partial credit for differentiation: Respondent attempts to explain how energy differs when it enters the atmosphere and when it leaves, but does so in such a way that is either too incomplete or incorrect to fit into category DD1. Category DD2 is therefore "partial credit" for DD1. As long as the participant references some kind of asymmetry in how light is reflected, bounced, changed, etc. (even if mostly wrong), they fall in category DD2 and not DD3.

DD3: Completely incorrect attempt to differentiate kinds of light/energy – This only applies to when there is absolutely NO asymmetry referenced.

DGHG: Definition of Greenhouse Gases

DGHG1: Greenhouse Gas "right *definition*" – Respondent may or may not mention the exact phrase "greenhouse gas", but at least defines them in the right context. Respondent defines greenhouse gases as molecules that *absorb* energy, not as molecules that trap, stop, block, or reflect energy. Respondent may use the terms light, heat, radiation, or infrared radiation instead of energy in their definition.

DGHG2: Greenhouse Gas "partial credit *definition*" – Respondent may have demonstrated an understanding of some of the elements outlined in category DGHG1 but their answer is either too grammatically vague to pass judgment on correctness or contains elements of *incorrect* content ("partial credit"). To get a definition code, the respondent has to mention or allude to energy. Remember that responses in this category do *not* describe greenhouse gases as molecules that "*absorb energy.*"

DGHG3: Not all gases are greenhouse gases: Respondent directly answers the question in Know_3 by stating in some way that not all gases are greenhouse gases.

DGHG4: Wrong concept of greenhouse gas: The participant holds obvious misconceptions about what a greenhouse gas is or how it works.

SGHG: Says/mentions greenhouse gases - If they give at least some definition or statement as to *what* greenhouse gases do or *how* they work, refer to DGHG categories.

SGHG1: *In know_1*: Simple mention of greenhouse gases (no explanation) –Participant uses the term "greenhouse gas," or provides a specific example, like carbon dioxide, in the context of a moderately or mostly *correct* explanation of climate change.

In know_2: Simple mention of greenhouse gases - participant uses the term "greenhouse gas," or provides a specific example, like carbon dioxide, in the context of a moderately or mostly *correct* explanation or strongly implied understanding of the concept of how energy functions in the atmosphere

In know_3: Simple mention of greenhouse gases - participant uses the term "greenhouse gas," or provides a specific example, like carbon dioxide, in the context of a moderately or mostly *correct* explanation or strongly implied understanding of the concept of a greenhouse gas.

SGHG2 : *In know_1*: Simple mention of greenhouse gases –Respondent uses the term "greenhouse gas," or provides a specific example of one, like carbon dioxide, in the context of a mostly *incorrect* explanation of climate change.

In know_2: Simple mention of greenhouse gases - participant uses the term "greenhouse gas," or provides a specific example, like carbon dioxide, in the context of a mostly *incorrect* explanation or strongly implied understanding of the concept of how energy functions in the atmosphere

In know_3: Simple mention of greenhouse gases - participant uses the term "greenhouse gas," or provides a specific example, like carbon dioxide, in the context of a mostly *incorrect* explanation or strongly implied understanding of the concept of a greenhouse gas.

SGHG3: Mentions greenhouse effect – Respondent explicitly uses the phrase "greenhouse effect," or some variation thereof. The respondent may or may not offer an explanation of what the greenhouse effect is or how it works.

MCC: Mechanism of Climate Change, broken up by concept

MCCE: Mechanism of climate change, **energy**

MCCE1: Atmosphere Retention time: Respondent describes how long it takes for heat to leave the atmosphere in depth. They reference that there are "more" greenhouse gases now than there were before, which causes heat to stay in the atmosphere longer OR causes *more* heat to stay in the atmosphere (either time or amount are permissible in this category). The explanation must be in the context of comparing a previous instance when greenhouse gases existed to the presence of greenhouse gases in the atmosphere today.

MCCE2: Trapped heat as a *mechanism* for climate change: Respondent describes heat/energy/radiation as being trapped. They may describe energy changes but lack a comparison from our time to a previous time with greenhouse gases. For inclusion in this category, the respondent must use the idea of "trapping" or "stopping" heat from leaving and must NOT attempt to use the concept of energy being "trapped" as a definition of greenhouse gases– that would fall into category DGHG2. However, there are responses that may be coded as both categories MCCE2 and DGHG2 if the respondent separately defines greenhouse gases, as guided by the definition of category DGHG2, and describes the mechanism of climate change as trapping heat.

MCCE3: Input rate/amount of energy does not equal output rate/amount of energy – Respondent demonstrated some knowledge that rate/amount of energy input is different from the rate/amount of energy output, and so energy is "stuck" somewhere OR energy is "slowed down." If the person does NOT reference a previous time with less GHGs, but does talk about heat being slowed or hindered from leaving the atmosphere, this category applies. Also, this category classifies responses that are vaguer than those in category MCCE2 or MCCE1.

MCCE4: Radiation from the sun directly heats the atmosphere – Respondent explicitly states or strongly implies that the atmosphere is heated by radiation from the sun. Respondent does not mention that Earth absorbs/reemits energy (i.e., the respondent skips differentiating energy).

MCCS: Mechanism of climate change, **source**

MCCS1: Human element: Respondent states or heavily implies that human emissions of greenhouse gases cause or contribute to global warming. This category includes references to fossil fuels and technology as causes of climate change.

MCCS2: Natural variation/weather patterns as an explanation for climate change: Respondent references natural variation in weather patterns as a cause of climate change thereby implying that anthropogenic emissions ("the human element") are not the only causes of climate change.

MCCS3: Pollution: Respondent explicitly states or strongly implies that pollution causes global warming, with no explicit reference to energy's function in the warming of the earth. This category also includes responses where the respondent seems to think that pollution physically "thickens the atmosphere" and thus causes warming. If the person references pollution (as opposed to greenhouse gases) as causing global warming, the response fits in this category.

MCCS4: Ozone: Respondent talked about the *depletion* of the ozone layer causing global warming.

MCCR: Mechanism of Climate Change, General Chemical **Reactions**

MCCR: Chemical Reactions and/or molecular properties explanations: participant attempts to explain the difference between energy entering Earth's atmosphere and energy exiting Earth's atmosphere from a strictly chemical perspective. Response does not include explicit differentiation between energies but rather uses chemical reactions in themselves as the cause of warming. A molecular perspective involving vibrations or other molecular properties may be used instead of chemical reactions or in addition to them. Response is too general to be given credit for categories DD1 or DGHG1.

MCCQ: Mechanism of Climate Change, **Confused Respondent**

MCCQ1: General Weather Confusion: Respondent thought we were asking about the seasons. The respondent may describe weather patterns, Earth's rotations, or the tilt of the Earth's axis.

MCCQ2: Did not understand: Respondent supplies a completely irrelevant answer (i.e. talks about high school perspectives).

DNK: Don't know or blank

DNK1: Don't know or N/A

DNK2: Code here if the participant uses a phrase similar to "I wouldn't add anything" or same as above.

Categories (organized by keyword)

Name of Category	Definition of Differentiation of Energy: DD In descending order from most thorough to least thorough	Distinctions:	Examples:
DD1	Respondent differentiates between visible sun light entering the atmosphere and infrared radiation/heat being emitted by the earth.	This category is fairly easy to find; if respondent say "reflected" IR (instead of absorbed and reemitted) that still fits here, provided that they made **some distinction** between light coming in and light going out.	"higher frequency radiation from the sun enters easily, but the lower frequency radiation reemitted by the cooler earth" (1Post) "the sun emits energy ans the earth absorbs that energy and then infared light comes back" (25Post)
DD2	Partial credit for differentiation: Respondent attempts to explain how energy differs when it enters the atmosphere and when it leaves, but	For example participant responses **may** include: -Failure to say how visible light becomes infrared	"Energy traveling to earth is converted to infared, [this energy can be absorbed by greenhouse gases]" (4Post).

	does so in such a way that is either too incomplete or incorrect to fit into category DD1. Category DD2 is therefore "partial credit" for DD1. As long as the participant references some kind of asymmetry in how light is reflected, bounced, changed, etc. (even if mostly wrong), they fall in category DD2 and not DD3.	-Failure to mention visible light AND infrared light (or heat) -Other **partially incorrect** attempts at differentiation	"The earth emits shorter wavelengths of energy whereas the sun emits longer ones." (6 Post)
DD3	Completely incorrect attempt to differentiate kinds of light/energy; this only applies to when there is absolutely NO asymmetry referenced	Fails to understand that there is a difference in incoming and outgoing energy.	"No difference on how energy travels." (27 Pre)

Name of category	Definition of Greenhouse Gas : DGHG In descending order from most thorough to least thorough	Distinctions:	Examples:
DGHG1	Greenhouse Gas "right *definition*" – Respondent may or may not mention the exact phrase "greenhouse gas", but at least defines them in the right context. Respondent defines greenhouse gases as molecules that *absorb* energy, not as molecules that trap, stop, block, or reflect energy. Respondent may use the terms light, heat, radiation, or infrared radiation instead of energy in their definition.	If you are having trouble deciding between DGHG1 and DGHG2, look at the context in which the definition of a greenhouse gas is given. Furthermore, if you really cannot tell what they are saying (because of grammar or vagueness) pick DGHG2. To be qualified in DGHG1, the respondent has to give some indication that they know *how* greenhouse work, not just that they cause something to happen, resulting in warming. (If respondent uses the concepts of trapping, stopping, blocking, or reflecting energy the response belongs in category DGHG2.) It doesn't matter for this category where the respondent thinks the energy comes from.	"Greenhouse gases absorb the reflected light…" (2Post) "Only the ones that can absorb infared light, like CO2 are considered greenhouse gases..."(3 Post)

DGHG2	Greenhouse Gas “partial credit *definition*” – Respondent may have demonstrated an understanding of some of the elements outlined in category DGHG1 but their answer is either too grammatically vague to pass judgment on correctness or contains elements of *incorrect* content (“partial credit”). To get a definition code, the respondent has to mention or allude to energy. Remember that responses in this category do *not* describe greenhouse gases as molecules that “*absorb energy.”*	Remember, this is the “Partial Credit” category. Cut-off: When respondent tries to explain the function of a greenhouse gas the response fits in DGHG2 when they do **not** say absorb.	“Climate change occurs due to the abundance of greenhouse gases in the atmosphere. Greenhouse gases, like co2, are slowly emitted into the atmosphere as energy, but as the abundance of this gas increases, it slowly warms up the earth, b/c greenhouse gases are created at a faster rate than they absorb infared light” (14 Post) “Carbon gases are released into the air that trap extra light” (16 Post)
DGHG3	Not all gases are greenhouse gases: Respondent directly answers the question in Know_3 by stating in some way that not all gases are greenhouse gases.	Just have to say “no” in some way, but do **not** have to understand why. Can also give counterexample to count in this category (e.g. saying, “N2 is not a greenhouse gas”).	“No, a greenhouse gas is referring to…” (21Pre) “not all gases are greenhouse gases. No clue what makes a greenhouse gas a greenhouse gas” (24Pre)
DGHG4	Wrong concept of greenhouse gas: The participant holds obvious misconceptions about what a greenhouse gas is or how it works.	If there is some modicum of correctness do **not** put the response here. Give them the credit for what they know.	“Greenhouse gases are the gases that remain in the earth's atmosphere. They are unable to leave” (30Pre)

Name of category	Says/Mentions Greenhouse Gases: SGHG In descending order from most thorough to least thorough	Distinctions:	Examples:
SGHG1	-*In know_1*: Simple mention of greenhouse gases (no explanation) – Participant uses the term “greenhouse gas,” or provides a specific example, like carbon dioxide, in the context of a moderately or mostly *correct* mostly	If they do **not** describe the behavior of greenhouse gases, examine the context. If they mention it in a moderately or mostly correct context, then the response fits in SGHG1. Parts of the response can be wrong or irrelevant, but if they use the term	“Climate change … can also be induced unnaturally by greenhouse gas buildup from carbon emissions” (13 Pre)

	correct explanation of climate change. -*In know_2:* Simple mention of greenhouse gases - participant uses the term “greenhouse gas,” or provides a specific example, like carbon dioxide, in the context of a moderately or mostly *correct* mostly *correct* explanation or strongly implied understanding of the concept of how energy functions in the atmosphere -*In know_3*: Simple mention of greenhouse gases - participant uses the term “greenhouse gas,” or provides a specific example, like carbon dioxide, in the context of a moderately or mostly *correct* mostly *correct* explanation or strongly implied understanding of the concept of a greenhouse gas.	greenhouse gases in a mostly correct context, SGHG1 is appropriate. This response does **not** fit into category DGHG1 because it does **not** say that greenhouse gases trap heat. Saying that GHGs cause warming does **not** give enough indication of understanding of *how* GHGs interact with energy. This response also does **not** fit into category MCCS3 because it does **not** specify that GHGs intrinsically cause warming.	
SGHG2	-*In know_1*: Simple mention of greenhouse gases –Respondent uses the term “greenhouse gas,” or provides a specific example of one, like carbon dioxide, in the context of a mostly *incorrect* explanation of climate change. -*In know_2:* Simple mention of greenhouse gases - participant uses the term “greenhouse gas,” or provides a specific example, like carbon dioxide, in the context of a mostly *incorrect* explanation or strongly implied understanding of the concept of how energy functions in the atmosphere -*In know_3*: Simple mention of greenhouse gases - participant uses the term “greenhouse gas,” or provides a specific example, like carbon dioxide, in the context of a mostly *incorrect*	Responses fit into category SGHG2 when they mention GHGs (or a type of GHGs) but do so in a mostly **incorrect** explanation. When participants refer to ozone depletion as the main cause of global warming, for example, it is **incorrect**. Because this response does **not** explain how GHGs work, and the context is incorrect, it fits into SGHG2.	“Climate change occurs when the weather patterns abruptuly change and are abnormal. It occurs because of greenhouse gases such as carbon dioxide released into the atmosphere.” (35 Pre)

	explanation or strongly implied understanding of the concept of a greenhouse gas.		
SGHG3	Mentions greenhouse effect – Respondent explicitly uses the phrase "greenhouse effect," or some variation thereof. The respondent may or may not offer an explanation of what the greenhouse effect is or how it works.	If respondent defines GHGs correctly and then mentions the greenhouse effect separately, SGHG3 and DGHG1 can be used to categorize the same response. However, usually SGHG3 is used in place of DGHG1.	"climate change occurs due to an increase of trapped infared light in our atmosphere which is caused by the greenhouse effect." (21 Post)

Name of category	Mechanism of Climate Change: MCC	Distinctions:	Examples:
ENERGY, Mechanism of Climate Change: **MCCE**			
MCCE1	Atmosphere Retention time: Respondent describes how long it takes for heat to leave the atmosphere in depth. They reference that there are "more" greenhouse gases now than there were before, which causes heat to stay in the atmosphere longer OR causes *more* heat to stay in the atmosphere (either time or amount are permissible in this category). The explanation must be in the context of comparing a previous instance when greenhouse gases existed to the presence of greenhouse gases in the atmosphere today	MCCE1 needs to have some sort of comparison to another time when there were not as many GHGs in the atmosphere. If they do not, then the response likely fits into MCCE2 or MCCE3. MCCE1 is the most specific category. Often there will be reference to "slowing" or "preventing" the escape of heat from the atmosphere	"Greenhouse gases absorb the reflected light and cause the earth to heat up (when more gases, slower rate of expulsion + therefore more heat" (2post) "but currently too much carbon gases are released into the air that trap extra light (heating earth up more than usual" (16 Post)
MCCE2	Trapped heat as a *mechanism* for climate change: Respondent describes heat/energy/radiation as being trapped. They may describe energy changes but lack a comparison from our time to a previous time with	This response fits into MCCE2 and **not** MCCE1 because it does **not** say that the more greenhouse gases there are in the atmosphere, the longer the energy stays in the atmosphere. Rather, it implies that there is a threshold beyond which energy "lingers" in the	"Climate change is a gradual heating of the Earth's atmosphere due to trapped heat" (30 post) "co2. that creates a layer in our planet's atmosphere which traps sunlight and

	greenhouse gases. For inclusion in this category, the respondent must use the idea of "trapping" or "stopping" heat from leaving and must NOT attempt to use the concept of energy being "trapped" as a definition of greenhouse gases– that would fall into category DGHG2. However, there are responses that may be coded as both categories MCCE2 and DGHG2 if the respondent separately defines greenhouse gases, as guided by the definition of category DGHG2, and describes the mechanism of climate change as trapping heat.	atmosphere. MCCE2 is almost MCCE1, but there is either a slight misunderstanding or miscommunication in the wording of the response (i.e., this category is partial credit). If energy being "trapped" is used to *define* a GHG, the response is coded in DGHG2 so as to avoid giving credit twice.	warms up the earth." (12 Pre)
MCCE3	Input rate/amount of energy does not equal output rate/amount of energy – Respondent demonstrated some knowledge that rate/amount of energy input is different from the rate/amount of energy output, and so energy is "stuck" somewhere OR energy is "slowed down." If the person does NOT reference a previous time with less GHGs, but does talk about heat being slowed or hindered from leaving the atmosphere, this category applies. Also, this category classifies responses that are vaguer than those in category MCCE2 or MCCE1.	If trying to decide between MCCE1, MCCE2, and MCCE3, first ascertain if there is a comparison to a different time with a different level of greenhouse gases. If yes, then MCCE1. Otherwise, look at the clarity: if they say heat is being STOPPED or TRAPPED, the response goes in MCCE2; if the response talks about how energy is slowed or hindered, then MCCE3.	"Cimate change is the heating up of the earth - above its normal temperature. It is caused by waves of heat leaving the earth's atmosphere, but certain greenhouse gases has caused the waves to leave even more slowly, causing the earth to be at a higher temperature." (6 post) "it releases infared light which gets absorbed by the greenhouse gases in our atmosphere causing the earth to heat up" (15 Post) – This is a good example of both a definition and a mechanism.
MCCE4	Radiation from the sun directly heats the atmosphere – Respondent explicitly states or strongly implies that the atmosphere is heated by radiation from the sun. Respondent	If the respondent only refers to radiation **from the sun** heating greenhouse gases, then it fits in MCCE4. In other words, it will **not** fit into category DD1 because it fails to explain differentiation. Additionally, if the mechanism	"The atmosphere traps energy traveling from the sun." (49 Pre)

	does not mention that Earth absorbs/reemits energy (i.e., the respondent skips differentiating energy).	by which energy from the sun reaches the Earth is ambiguous and there are no clear indications in the rest of the response to suggest that the energy reaches the Earth's surface, then the response should be classified in MCCE3.	
SOURCE, Mechanism of Climate Change: **MCCS**			
MCCS1	Human element: Respondent states or heavily implies that human emissions of greenhouse gases cause or contribute to global warming. This category includes references to fossil fuels and technology as causes of climate change.	This category will include any reference to how humans cause climate change, e.g. the Industrial Revolution, cars, oil combustion, etc.	"Greenhouse gases emited by our cars, and industrial process and other human activity involving the burning of fossil fues or other combustables" (18 Pre)
MCCS2	Natural variation/weather patterns as an explanation for climate change: Respondent references natural variation in weather patterns as a cause of climate change thereby implying that anthropogenic emissions ("the human element") are not the only causes of climate change.		"Climate change is a natural process (ice age - el nino) an can also be induced unnaturally by greenhouse gas buildup from carbon emissions" (13 Pre)
MCCS3	*MCCS3*: Pollution: Respondent explicitly states or strongly implies that pollution causes global warming, with no explicit reference to energy's function in the warming of the earth. This category also includes responses where the respondent seems to think that pollution physically "thickens the atmosphere" and thus causes warming. If the person references pollution (as opposed to greenhouse	This category needs some sort of implication that humans or "waste" emissions warm up the atmosphere by themselves, with no regard for energy's role.	"We produce too much carbon as waste. It ends up in the atmosphere. Heats up." (31 Pre)

	gases) as causing global warming, the response fits in this category.		
MCCS4	*MCCS4*: Ozone: Respondent talked about the *depletion* of the ozone layer causing global warming.	If the respondent claims that ozone depletion causes climate change, it goes into MCCS4.	"ozone depletion also affect how the sun's heat and light is absorbed in our atmosphere and cause climate change." (28 Pre)
GENERAL CHEMICAL REACTIONS, Mechanism of Climate Change: **MCCR**			
MCCR	Chemical Reactions and/or molecular properties explanations: participant attempts to explain the difference between energy entering Earth's atmosphere and energy exiting Earth's atmosphere from a strictly chemical perspective. Response does not include explicit differentiation between energies but rather uses chemical reactions in themselves as the cause of warming. A molecular perspective involving vibrations or other molecular properties may be used instead of chemical reactions or in addition to them. Response is too general to be given credit for categories DD1 or DGHG1.	Responses fit into this category if they provide a very general attempt to describe heat in the atmosphere. Often the respondent has misconceptions about the role of chemicals in the atmosphere and therefore their response **cannot** fit into categories DD1 or DGHG1 as well as this one.	"The sun directly enters the earth causing many chemical reactions. The earths byproducts of these chemical reactions let out either heat or molecules. Some molecules reabsorb the heat and create global warming" (5 post) "Energy travels to the earth from the sun in the rays of heat of the sun in the form on molecules in constant motion. Energy travels away from earth by the same force of interacting and fast moving molecules" (6 pre)
RESPONDENT CONFUSION, Mechanism of Climate Change: **MCCQ**			

MCCQ1	General Weather Confusion: Respondent thought we were asking about the seasons. The respondent may describe weather patterns, Earth’s rotations, or the tilt of the Earth’s axis.	Respondent could talk about seasons in conjugation with actual explanation of global warming. Read the whole response before coding.	“Climate change occurs when the sun is hitting the earth from a different angle. When it is winter, the sun's rays are less direct. In the summer, there are longer days w/ more direct sunlight” (21 Pre)
MCCQ2	Did not understand: Respondent supplies a completely irrelevant answer (i.e. talks about high school perspectives).		“It is senior year that students begin to get tired of the hgh school environment and are anxious to open a new chapter of their lives: colege. This is called senioritis. Therefore a climate change occurs to a senior in highschool when he/she is ready to leave high school and move on” (6 Pre)

Number of Category	Don’t know: DNK	Distinctions:	Examples:
DNK1	N/A: maybe ran out of time.		“I do not know how climate change occurs I was never taught.” (24Pre)
DNK2	Code here if the participant uses a phrase similar to “I wouldn’t add anything” or “same as above.”		“I wouldn’t add anything.” (3 Post)

Notes on Choosing Codes

This “crib sheet” (with following diagram-figure) was generated to identify a single defining characteristic and/or unique distinction within each code. Here are a few notes on how it was used:

- The crib sheet is NOT self-contained. It is meant to jog memory without having to constantly flip through the coding packet. The sheet is most useful if one is generally familiar with the coding scheme already.
- Assigning a code should be defensible with explicit references to the definitions and explanations of that code as provided in the packet.
- DGHG3 is separated from the other DGHG codes intentionally (that is, DGHG3 coming after DGHG4 is NOT a typo).
- SGHG codes are only supposed to be used in the complete absence of a definition of GHGs. The SGHG category is primarily useful in coding for whether an explanation of climate change includes explicit reference to GHGs.
- Use MCCE codes to identify how a participant refers to energy within an explanation of climate change.
- Enquoted words are things that must appear in a response in order to apply the code (except when there are other options–for example, SGHG1 requires using the phrase ”GHG” *or* citing specific examples of GHGs).

Following is the “crib sheet” itself:

DD1: visible incoming & infrared outgoing

DD2: asymmetry/difference reference

DD3: wrong, no asymmetry/difference

DGHG1: GHGs ”absorb” energy

DGHG2: part correct, no ”absorb”

DGHG4: wrong

DGHG3: ”not all”, cite >1

SGHG1: ”GHG”/e.g., mostly accurate

SGHG2: ”GHG”/e.g., mostly wrong

SGHG3: ”greenhouse effect”

MCCE1: more gas/heat than before

MCCE2: heat/energy ”trapped”

MCCE3: different input/output rates/amounts

MCCE4 sun’s radiation heats atmosphere

MCCS1: humans/tech/fossil fuels

MCCS2: natural variation

MCCS3: pollution

MCCS4: O_3 layer

MCCR: chemical/molecular exclusively

MCCQ1: weather, confusion

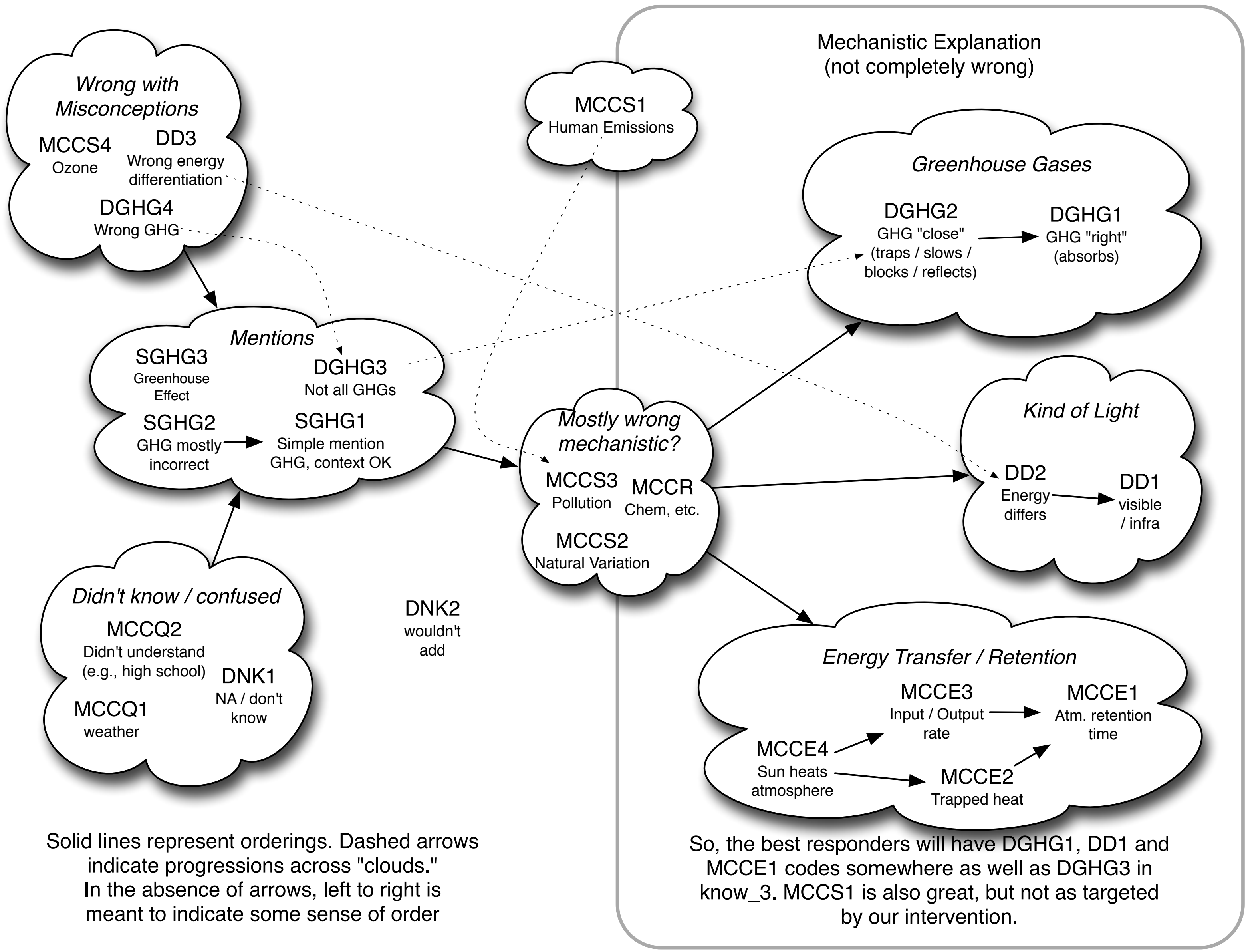
MCCQ2: irrelevant

DNK1: ”don’t know”, n/a

DNK2: nothing added

As a kind of additional crib-sheet, coders also received the figure on the following page.

It provides a rough, “at a glance,” graphical scheme (“bubble-diagram”) that offers a perspective on the relationships among the codes. See the figure for more details.


Mechanistic Explanation
(not completely wrong)
Wrong with Misconceptions
MCCS4
Ozone
DD3
Wrong energy differentiation
DGHG4
Wrong GHG
MCCS1
Human Emissions
Greenhouse Gases
DGHG2
GHG "close" (traps / slows / blocks / reflects)
DGHG1
GHG "right" (absorbs)
Mentions
SGHG3
Greenhouse Effect
DGHG3
Not all GHGs
SGHG2
GHG mostly incorrect
SGHG1
Simple mention GHG, context OK
Mostly wrong mechanistic?
MCCS3
Pollution
MCCR
Chem, etc.
MCCS2
Natural Variation
Kind of Light
DD2
Energy differs
DD1
visible / infra
Didn't know / confused
MCCQ2
Didn't understand (e.g., high school)
DNK1
NA / don't know
MCCQ1
weather
DNK2
wouldn't add
Energy Transfer / Retention
MCCE3
Input / Output rate
MCCE1
Atm. retention time
MCCE4
Sun heats atmosphere
MCCE2
Trapped heat
Solid lines represent orderings. Dashed arrows indicate progressions across "clouds."
In the absence of arrows, left to right is meant to indicate some sense of order
So, the best responders will have DGHG1, DD1 and MCCE1 codes somewhere as well as DGHG3 in know_3. MCCS1 is also great, but not as targeted by our intervention.

Appendix S4: *Experiment 3's Additional Surprise / Embarrassment Items*

Experiment 3 further enhanced Experiment 2 (and its 400-word stimulus) by adding three items to the immediate posttest to better elicit introspection (about surprise and embarrassment; see Clark, 2013, offer more detail.) The extra items were:

1. Did you find anything in this explanation surprising? [Rated on a 9-point scale from "Not Surprising" to "Extremely Surprising"]
2. Were you surprised (or even embarrassed) at your own lack of knowledge? [Rated on a 9-point scale from "Not Surprised" to "Extremely Surprised"]
3. Consider the information in the description provided above compared to the information you recalled for your own description. Please provide an approximate breakdown of how much knowledge was genuinely new compared to how much information you had seen before (but forgot)? [Rated on a 9-point scale from "I don't remember seeing any of this information before' to "I have seen all of this information before"]

Appendix S5: *Experiment 5's Curriculum*

After each day's estimation activity, students received a 15-minute lesson relating to the mechanisms of global warming. Monday's lesson consisted of an exploration of an interactive simulation, PhET, on the greenhouse effect, which was developed by the University of Colorado (2011). The simulation was projected on a screen for the class and the experimenter guided them through the exploration. The students were all given a worksheet where they wrote their observations of the simulation (see below). As a class, we examined the overall greenhouse effect with various concentrations of greenhouse gases in the atmosphere. Students observed the behavior of visible light photons (represented by yellow dots) and infrared photons (represented by red dots) in the atmosphere. They then observed a simulation of carbon dioxide, methane, water, molecular nitrogen, and molecular oxygen on the molecular scale. The simulation shows that infrared photons get absorbed and are emitted later by carbon dioxide, methane, and water while passing straight through nitrogen and oxygen. It also shows visible light photons passing straight through all the gases. Wednesday's lesson consisted of explicit instruction on the mechanisms of global warming using a PowerPoint presentation, based on a part of Ranney et al.'s (2012) 400-word text. Friday's lesson was also a PowerPoint presentation on the sources of greenhouse gases and the consequences of global warming. Table S1 below summarizes the activities for each day, and immediately below are the worksheet's activities and queries-for-students related to the PhET simulation:

Observe the greenhouse effect today.

A. What kinds of light are shown? What are the differences between the behavior of each?

B. Follow one photon of each, write observations of the behavior of each photon.

Observe the simulation of no greenhouse gas concentration and lots of greenhouse gas concentration

C. Now write down observations for no greenhouse gas concentration and lots of greenhouse gas concentration.
What differences do you see?

D. Now let's see what is happening on the molecular level. Write down observations as we go through each molecule.

1. CH_4
2. CO_2
3. H_2O
4. O_2
5. N_2
6. Which ones are greenhouse gases? How are they different from the ones that are not?

Table S1: Activity Timeline

Day	*Mechanism-Plus* Group	*Mechanism-Only* Group
-3	Pre-Test	
Mon.	Estimation 1: Through 2006, the number of years from 1995 to 2006 that rank among Earth's 12 hottest years [11] Estimation 2: % change (since 1960s) in world ocean ice coverage [+40%]	Estimation 1: Number of people in Sub-Saharan Africa living with HIV [22.9 million] Estimation 2: U.S. Population [311 million]
	PhET Greenhouse Effect Simulation	
Wed.	Estimation 1: % change (1959 to 2009) in atmospheric CO_2 [+22.5%] Estimation 2: % change (since 1750) in atmospheric CH_4 [+151%]	Estimation 1: % Americans over 25 years old w/ a Bachelor's degree [30%] Estimation 2: # U.S. residents incarcerated per 1000 residents [7.4]
	Powerpoint on GW Mechanisms	
Fri.	Estimation 1: Change (1870-2004) in sea-level [+.195m] Estimation 2: % change (from 1970 to 2003) in annual number of Earth's disasters [+300%]	Estimation 1: U.S. unemployment rate [8.3%] Estimation 2: Lifetime odds of being murdered in the U.S. [1 in 211]
	Powerpoint on GW causes and consequences	
+34	Post-Tests	

Appendix S6: Format of Experiment 6's "Representative" NDI Intervention

Experiment 6 largely consisted of an adaptation of the paper-and-pencil survey (as shown in Appendix S2) to the Qualtrics Inc. (Provo, UT) system. The intervention, however, was completely different—focusing on numerical estimation rather than mechanistic description. Below, a single example is given of a numerical estimation. Note that unlike in the pencil-and-paper NDI intervention of Experiment 7, we did not elicit policy / funding preferences in this online intervention.

Please estimate the following quantity. First, you must select the choice that corresponds to the format for your estimate - even if there is only one choice! Then, please write the number *by itself*.

According to observation data collected at Mauna Loa Observatory in Hawaii, what is the percent change in atmospheric CO_2 levels from 1959 (when observation began) to 2009?

My estimate is a...

○ % increase (in CO2) ○ % decrease (in CO2)

The number I estimate is (whole numbers only):

How low and how high would that number have to be to surprise you? If you wrote decrease above, and one of your answers is an increase (or vice versa) use the minus sign (-) to indicate the opposite direction, and put that number in "Below." Your "Above" answer should *always* be the same direction as your estimate (and probably larger)!

Below:

Above:

Approximately how confident are you that the actual value falls in the range between the *low* and *high* numbers above? (Note that a confidence below 50 would imply you think it is *more likely* that the number is *outside* your range!)

	Unsure				Moderately Sure				Totally Sure		
	50	55	60	65	70	75	80	85	90	95	100
Percent Confidence											

Appendix S7: *Experiment 7's UN Development Programme (UNDP) Millennium Goals and Climate-Related Funding Choices*

Experiment 7 describes a series of fund allocation policy decisions made by participants. Below are the instructions given to participants in our two-item intervention, followed by the text used to describe the two alternatives for each item.

Funding Policy Instructions Given Subjects

As a result of the UN Millennium Summit, in the year 2000, the United Nations adopted eight goals for increasing the economic and social conditions of the world's poorest countries, called the Millennium Development Goals. These goals are to: (1) end poverty and hunger, (2) achieve universal primary education, (3) promote gender equity, (4) reduce child mortality rates, (5) improve maternal health, (6) combat HIV/AIDS and other diseases, (7) ensure environmental sustainability, and (8) develop a global partnership for development.

Imagine that you have been hired as a consultant to the United Nations. Your task is to allocate funds between projects oriented toward global climate change and projects focused on achieving other Millennium Development Goals. You will provide from two to four policy allocations in total.

For each policy, first you will be asked to estimate the value of a policy-relevant statistic. Then you will make an initial policy recommendation. You will be asked to describe your estimation process—in particular, what knowledge and reasoning you used to make your estimate. (You will write all of this information inside of this packet.)

After making an initial recommendation for each of the Millennium Development Goals, you will be given the true values of the statistics, as well as an opportunity to revise each recommendation you made.

Funding Alternatives

All four variants of Experiment 7's two-item group's intervention used the same policy choices. The first (policy one) choice was:

1. Create initiatives to reduce extreme poverty and hunger; or
2. Invest in new technologies to reduce the levels of greenhouse gases in the atmosphere.

The second (policy two) choice was:

1. Invest in providing sustainable access to safe drinking water and basic sanitation; or
2. Invest in renewable energy technologies, such as solar and wind power.