

UC Berkeley

UC Berkeley Previously Published Works

Title

Climate Change Conceptual Change: Scientific Information Can Transform Attitudes.

Permalink

<https://escholarship.org/uc/item/5rv6s50g>

Journal

Topics in cognitive science, 8(1)

ISSN

1756-8757

Authors

Ranney, Michael Andrew

Clark, Dav

Publication Date

2016

DOI

10.1111/tops.12187

Supplemental Material

<https://escholarship.org/uc/item/5rv6s50g#supplemental>

Peer reviewed



Topics in Cognitive Science 8 (2016) 49–75
Copyright © 2016 Cognitive Science Society, Inc. All rights reserved.
ISSN:1756-8757 print/1756-8765 online
DOI: 10.1111/tops.12187

Climate Change Conceptual Change: Scientific Information Can Transform Attitudes

Michael Andrew Ranney,^a Dav Clark^b

^aGraduate School of Education and Department of Psychology, University of California, Berkeley

^bD-Lab and Berkeley Institute for Data Science, University of California, Berkeley,

Received 27 July 2014; received in revised form 16 February 2015; accepted 28 August 2015

Abstract

Of this article's seven experiments, the first five demonstrate that virtually no Americans know the basic global warming mechanism. Fortunately, Experiments 2–5 found that 2–45 min 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 (noncausal) correlational data. Our studies evidenced *no* polarizations. Finally, we introduce HowGlobalWarmingWorks.org—a website designed to directly enhance public “climate-change cognition.”

Keywords: Global warming; Climate change; Conceptual change; Cognitive psychology; Science education; Attitude change; Cultural polarization; HowGlobalWarmingWorks.org

Correspondence should be sent to Michael Andrew Ranney, Graduate School of Education, University of California, Berkeley, 4655 Tolman Hall, Berkeley, CA 94720-1670. E-mail: ranney@berkeley.edu

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 et al. (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.

1. Introduction

People are well-informed about various topics, but *some* scientific knowledge has not infused nonspecialists' 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 et al., 2015; 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 experiments²—and a website—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 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 et al., 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-nurture³ “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, this issue; 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 (2013b, p. ED32A-08) recently wrote, regarding the “public conflict over climate change,” that “efforts to promote civic science literacy cannot 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 et al., 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 United States (Davenport & Connelly, 2015) from virtually 0% a few decades ago—despite a few recent changes in political rhetoric (cf. since the film *An Inconvenient Truth* was released).

2. 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, and natural selection). Anthropogenic global warming likewise triggers media whirlwinds—generally of claims about current or projected climate effects (e.g., sea acidification and species’ reductions). 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, although 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 and heat-sensors' positionings), 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 nonnatural 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.

3. 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., 2012, Kahan, Jenkins-Smith, Tarantola, Silva, & Braman, 2015; McCright et al., this issue; Sundblad, Biel, & Gerling, 2007;—e.g., regarding how CO₂ 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 (a) modest, yet (b) related to acceptance/attitudes.

3.1. Method

3.1.1. 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 subgroup) 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.

3.1.2. Materials

The 10- to 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 interrater reliability; mean $\kappa > 0.7$), (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 (see Appendix S1, etc. of the Supplemental Materials for more details).

3.2. 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 0.65 (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 ($r = 0.22$, $p = 0.0002$) and anthropogenic ($r = 0.17$, $p = 0.005$). Suggesting that such knowledge is behaviorally potent, anthropogenic climate-change acceptance was significantly associated with sacrifice willingness for *all four* willingness-to-sacrifice items ($\chi^2(4) > 32$, $p < 0.001$)—and subjects' knowledge scores significantly associated with *two* of those four items ($\chi^2(1) = 3.9$, $p < 0.05$, and $\chi^2(1) = 16.7$, $p < 0.001$, 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 population⁷—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 multisite project that we are collaborating in has more recently also found another (United States) link between mechanistic knowledge and global warming acceptance—both anthropogenic and existential acceptance. Relatedly, Arnold et al. (2015) 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 1-month-delay postintervention tests. Initial German mechanistic knowledge, like the Americans', was low—only 18% accuracy (1.6 on a 0–9 scale)—yet Arnold et al. (2015) 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 et al.

(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 et al., 2007, and Swiss subjects studied by Tobler et al., 2012) indicates that climate-change knowledge correlates with beliefs aligning with scientific evidence. Likewise, Stevenson, Peterson, Bondell, Moore, and Carrier (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 10 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 11th study, see Otto & Kaiser, 2014).

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

4. 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., 2015, 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 et al., 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 (a) understand and significantly retain the information—perhaps with notable longevity—and (b) adopt attitudes and beliefs more aligned with the scientific consensus's mechanistic explanation (e.g., Lewandowsky, Gignac, & Vaughan, 2013; Maibach, Leiserowitz, & Gould, 2013).

5. 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).

5.1. Method

5.1.1. 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 (a) provided global warming explanations and filled out knowledge and attitude surveys, (b) read the 400-word explanation of global warming’s mechanism and rated their experienced surprise, (c) were retested (identically to the pretest) on their knowledge and attitudes, and (d) answered demographic questions.

5.1.2. Materials

Our attitude survey included 12 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 (a) how global warming works (so a high school senior could understand it), (b) differences in how energy/heat/light travels from the Sun to the Earth versus travels away from the Earth, and (c) what makes something a greenhouse gas (if not all gases are greenhouse gases); interrater reliability of scored queries was again high: mean $\kappa = 0.7$. (Appendices S2 and S3 of the Supplemental Materials offer more details.)

5.2. 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 the Earth); after reading our 400 words, though, most subjects (59%) correctly answered that the Earth emits *infrared* light ($p < 0.0001$). 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 < 0.01 for (a) and (b) subscores *separately* for Berkeley and Brownsville subjects; p ’s < 0.05 for the same tests for (c)). Crucially, global warming acceptance also increased after our brief intervention (Brownsville: $t(39) = 4.24$, $p < 0.0001$; Berkeley: $t(72) = 2.28$, $p = 0.01$), 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— $r = 0.39$, $p = 0.01$ —but not Brownsville, students: $r = 0.15$, $p = 0.55$).

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 2 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.

6. Experiment 3: Online replication and longevity extension

How durable are Experiment 2’s attitude changes? Experiment 3 probed for such changes about 4 days after 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.

6.1. Method

6.1.1. 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 preintervention—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 ($M = 4$) postintervention—a range planned to assess the retention time-course for later studies.

6.1.2. 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. (Appendix S4 of the Supplemental Materials—and Clark, 2013—offers more details.)

6.2. Results and discussion

The results replicated Experiment 2—and extended them by finding that postdelay gains remained. Scored knowledge again correlated with self-rated knowledge ($r = 0.5$, $p < 0.0001$), to roughly the same degree found for Experiment 2’s UCB students. On 0–9 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 < 0.00001) 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)—notable¹¹ gains (again) for a 400-word text (immediate posttest: $t(79) = 2.5$, $p = 0.006$; delayed posttest: $t(79) = 1.7$, $p = 0.05$). The largest posttest global warming agreement gains arose from items assessing (a) certainty of global warming’s occurrence and (b) humans largely causing it (0.19 and 0.25 gains, respectively). Likewise, subjects’ mean self-rated knowledge increased markedly from pre- to posttest (4.5–5.6; also replicating Experiment 2)—and yielded a delayed posttest gain that was also robustly significant ($M = 5.2$; both posttests’ gains yielded z ’s > 5.9 ; p ’s < 0.00001).

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 polarization¹² phenomena that have concerned others (e.g., Kahan et al., 2012; cf. Lord et al., 1979).

7. 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.

7.1. Method

7.1.1. Subjects, design, procedure, and materials

At 58% democratic, our 41 subjects (45% female) were overrepresented to about the same degree as is typical of MTurk samples (Richey & Taylor, 2012; see Clark, 2013). Mean self-rated conservatism 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-inconsistency, as checked for in 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—again using the 400-word mechanistic explanation as the intervention.

7.2. 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 < 0.001). Global warming acceptance ratings increased significantly from a 6.3 pretest mean to a 6.6 posttest mean ($z = 3.45$; $p = 0.001$)—and the delayed posttest's score was maintained ($M = 6.6$, $z = 2.84$; $p < 0.005$). 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 conservatism and mean global warming acceptance gains was *not* significant and basically zero ($r = -0.03$, $p = 0.85$), 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 nonpolarization 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.

8. 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 and 4 yielded dramatic gains in knowledge and marked attitude changes upon delayed posttesting, their retention periods of about 5 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 5 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 postintervention 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.

8.1. Method

8.1.1. Subjects

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

8.1.2. Design, procedure, and materials

Experiment 5's curriculum alternated between (a) mechanistic global warming explanations related to Experiments 2–4 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* (quasicontrol) group ($n = 30$) received the mechanistic intervention—but with six *unrelated*, nonkey statistics instead. Subjects received 15 min of mechanistic global warming instruction on 1 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 (a) a common molecular-level (and molecule-concentration-level) greenhouse effect simulation (PhET; University of Colorado, 2011), (b) a six-slide presentation on global warming's mechanism (based on a subset of Experiments 2–4's 400 words), and (c) 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-*unrelated*, 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 nonimmediate posttest (3 days later; $N = 63$), and a delayed posttest (34 days later; $N = 59$). (See Appendix S5 and Table S1 of the Supplemental Materials—and Felipe, 2012—for more details on Experiment 5's curricula, for which statistics were addressed when and by whom, or for additional results.)

8.2. 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 et al. (2013). Main

predictions were (a) that mechanistic explanations would yet again yield global warming understanding gains *and* more pro-environmental attitudes, (b) that the key statistics would enhance such effects, and (c) that the effects would be detected 5 weeks later.

Pretest mechanistic knowledge was virtually zero—consistent with Experiments 1 and 4’s non-University results. However, the 45-min curriculum markedly improved both groups’ explanations: They more correctly included basic mechanistic concepts in average scored values (mechanism-plus-statistics group: $t(32) = 7.02$; $p < 0.0001$; mechanism-only group: $t(29) = 6.12$; $p < 0.0001$; respective means increased from 0.06 to 1.20 and from 0.07 to 0.98 on a 0–4 scale). The combined groups’ 3-day delay EBI posttest gain was also notable ($t(62) = 5.91$, $p < 0.00001$; 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 important, 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 < 0.003), which seems notable for 0.005 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: $t(32) = 1.76$, $p < 0.05$.) 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 (+0.8 vs. +0.3; $t(48.7) = 2.61$, $p < 0.01$; 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 (cf. Ranney, Munnich, & Lamprey, in press)—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).

9. 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 et al., 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 et al., 2007; also see Garcia de Osuna et al., 2004), we hypothesized that representative statistics' surprising feedback values¹³ would increase subjects' climate-change acceptance, yet diminish self-confidence in their climate-change knowledge.

9.1. Method

9.1.1. 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 conservatism self-rating was 4.0 ($SD = 2.1$, with all ratings on 1–9 scales)—comparable to that of our experiments with undergraduates.

9.1.2. Design, procedure, and materials

Instructional and survey materials paralleled Experiment 4, with the central difference that a numeric intervention similar to part of Experiment 5—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 consensus¹⁴ item. (Appendix S6 of the Supplemental Materials—and Clark, 2013—offers more details.)

9.2. Results and discussion

Experiment 6's intervention succeeded (cf. Clark et al., 2013's, Study 3)¹⁵ in significantly increasing global warming acceptance/concern ratings from pretest to posttest ($M = 6.4$ and 6.8 —a gain of 15% of the 1–9 scale's "available room;" $t(37) = 2.74$, $p < 0.005$). 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 conservatism and one's global warming acceptance increase was *not* significant and effectively zero ($r = -0.07$, $p = 0.67$)—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; see Ranney et al., in press) 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; Ranney et al., in press). As anticipated based on prior NDI studies, these largely surprised subjects reported feeling less knowledgeable, postfeedback ($M = 4.2$), than prefeedback ($M = 5.2$; $t(37) = -3.38$, $p < 0.001$). 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.

10. 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 the Earth cooled *slightly* by 0.2°F during 1940–1975 (Jastrow, Nierenberg, & Seitz, 1991). The tiny dip—only 0.04% in °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, 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.

10.1. Method

10.1.1. Subjects

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

10.1.2. 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 postfeedback policy *changes* regarding/versus various UN (UNDP) goals. (See Appendix S7 of the Supplemental Materials 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.

10.2. Results and discussion

As predicted, climate-change acceptance significantly dropped—from pre- to posttest for the two-item group ($M = 6.5$ and 6.2 ; $t(42) = -4.3$, $p < 0.0001$)—and dipped further to 5.9 for the eight-item group (dropping about 11% of the available room, $t(88.6) = -2.61$, $p < 0.005$). As these mean shifts were toward ambivalence (a “5” rating), they seemed to reflect confusion rather than nonacceptance. Indeed, as predicted, self-rated knowledge (a) fell from a 5.0 pretest mean to 4.5 for the two-item group ($t(44) = -2.5$, $p < 0.01$) and (b) plummeted to 2.9 following all eight items ($t(87.2) = -5.3$, $p < 0.00001$). 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 ($\chi^2(1) = 22$, $p < 0.01$) versus *all* eight nonclimate 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 ($r = 0.009$, $p = 0.95$)—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).

11. 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 et al. (2013b), therefore, produced five videos—from 52 s to 4.7 min (83–596 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; see Ranney et al., in press). 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. (2015) have already found that our 4-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

12. 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. (2015) with German subjects. Fortunately, Experiments 2–5 and Arnold et al.’s (2015) 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., 2015) 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 *unrepresentatively* 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 the discussion following Experiment 1’s results, 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 (2015) German replications of Experiment 1.

Experiments 2–6’s interventions (and Arnold et al., 2015) 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 correlation²⁰ 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 et al., 2013, similarly found 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., 2015) 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., nonmechanistic 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.

12.1. 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 preinstruction full-credit knowledge were 0.22 (San Diego denizens), 0.26 (Berkeley [.33] and Brownsville [.11] undergraduates), 0.42 (Berkeley undergraduates), 0.21 (MTurk subjects), and 0.02 (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* posttest 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 3-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 9 days; see Ranney et al., in press). (Experiment 7’s misleading-statistics acceptance change was –11% of the “available room”—i.e., toward extreme *disagreement*—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 posttesting. 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 (a) longer interventions, (b) reminders of the interventions’ contents, and/or (c) *combinations* of the interventions discussed above (e.g., from Experiments 4-6, 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.-centric provincialism; see Ranney et al., in press).

12.2. 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; see 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 5 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; Ranney et al., in press), we can quickly cause more people to (a) accept global warming’s reality (as climatologists see it), (b) express concern about it, and (c) orient toward action regarding it. Naturally, *intentions* to act are not *actions*, but they are often actions’ precursors.

Acknowledgments

We especially thank Lee Nevo Lamprey, Sarah Cohen, Kimberly Le, and Daniel Reinholz, as well as Shirley Hu, Lisa Zhang, Oliver Arnold, Matthew Shonman, Kyle Fricke, Lloyd Goldwasser, Rachel Ranney, Jeff Wilson, Florian Kaiser, Ed Munnich, Patricia Schank, Ryunosuke Fujinomaki, Charles Chang, Ron Cohen, Liam Gan, Brad Balukjian, Danyal Kazmi, Michelle Million, and the Reasoning Group at the University of California, Berkeley (UCB), for contributions that led to this article. This study was supported by UCB’s Committee on Research and an Institute of Education Sciences predoctoral training grant (R305B090026).

Notes

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 antiempirical, 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 < 0.01; 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, Kashima, Walker, and O'Neill (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 preinformation explanation/theory elicitation *increase* surprise—and *reduce* post hoc rationalization/hindsight (Clark & Ranney, 2010; Munnich, Ranney, & Song, 2007; cf. Rinne et al., 2006, whose PEIC procedure is partly used in Experiments 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 min.
12. We use "polarization" in a high-threshold sense (akin to Lord, Ross, & Lepper, 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 et al., 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 the results of Fernbach, Rogers et al. (2013); 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 geo-engineering 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.”

References

- Arnold, O., Teschke, M., Walther, J., Lamprey, L. N., Lenz, H., Kaiser, F. G., & Ranney, M. A. (2015). Increasing global warming knowledge and acceptance by directly web-disseminating scientific information. Paper presented at the 15th Annual Education Research Day, Berkeley, CA.

- Bord, R. J., Fisher, A., & O'Connor, R. E. (1998). Public perceptions of global warming: United States and international perspectives. *Climate Research, 11*(1), 75–84.
- Clark, D. J. (2013). Climate change and conceptual change. Doctoral dissertation. Available at https://github.com/davclark/UCB_thesis/releases. Accessed December 30, 2013.
- Clark, D., & Ranney, M. A. (2010). Known knowns and unknown knowns: Multiple memory routes to improved numerical estimation. In K. Gomez, L. Lyons, & J. Radinsky (Eds.), *Learning in the disciplines. Proceedings of the 9th international conference of the learning sciences* (Vol. 1, pp. 460–467). Chicago, IL: International Society of the Learning Sciences, Inc.
- Clark, D., Ranney, M. A., & Felipe, J. (2013). Knowledge helps: Mechanistic information and numeric evidence as cognitive levers to overcome stasis and build public consensus on climate change. In M. Knauff, M. Pauen, N. Sebanz, & I. Wachsmuth (Eds.), *Cooperative minds: Social interaction and group dynamics. Proceedings of the 35th Annual Meeting of the Cognitive Science Society* (pp. 2070–2075). Austin, TX: Cognitive Science Society.
- Coady, D., Parry, I., Sears, L., & Shang, B. (2015). How large are global energy subsidies? IMF Working Paper No. WP/15/1015. International Monetary Fund.
- Cohen, S. (2012). San Diego's IPCC: The implications and politics of climate change confusion. Undergraduate thesis, University of California, Berkeley.
- Davenport, C., & Connelly, M. (2015). Most Americans support government action on climate change, poll finds. *The New York Times* [Online]. Available at <http://www.nytimes.com/2015/01/31/us/politics/most-americans-support-government-action-on-climate-change-poll-finds.html>. Accessed January 30, 2015.
- Edx.org/understanding-climate-denial (2015). UQx Denial 101x 6.7.4.1 Full interview with Michael Ranney. Available at <https://youtu.be/EIRSUGRo4dU>. Accessed July 20, 2015.
- Felipe, J. (2012). *Numerical reasoning, knowledge, and environmental behavior regarding climate change*. Masters project, Graduate School of Education, University of California, Berkeley.
- Fernbach, P. M., Rogers, T., Fox, C. R., & Sloman, S. A. (2013). Political extremism is supported by an illusion of understanding. *Psychological Science, 24*, 939–946. doi:10.1177/0956797612464058
- Fernbach, P. M., Sloman, S. A., St. Louis, R., & Shube, J. N. (2013). Explanation friends and foes: How mechanistic detail undermines understanding and preference. *Journal of Consumer Research, 39*, 1115–1131. doi:10.1086/667782
- Garcia de Osuna, J., Ranney, M., & Nelson, J. (2004). Qualitative and quantitative effects of surprise: (Mis)estimates, rationales, and feedback-induced preference changes while considering abortion. In K. Forbus, D. Gentner, & T. Regier (Eds.), *Proceedings of the Twenty-Sixth Annual Conference of the Cognitive Science Society* (pp. 422–427). Mahwah, NJ: Erlbaum.
- Guy, S., Kashima, Y., Walker, I., & O'Neill, S. (2014). Investigating the effects of knowledge and ideology on climate change beliefs. *European Journal of Social Psychology, 44*, 421–429. doi:10.1002/ejsp.2039
- Harte, J., & Harte, M. E. (2008). Cool the Earth, save the economy: Solving the climate crisis is EASY. Available at <http://www.cooltheearth.us/>. Accessed July 18, 2014.
- Jastrow, R., Nierenberg, W., & Seitz, F. (1991). Global warming: What does the science tell us? *Energy, 16* (11–12), 1331–1345. doi:10.1016/0360-5442(91)90006-8
- Kahan, D. M. (2013a). Ideology, motivated reasoning, and cognitive reflection. *Judgment and Decision Making, 8*, 407–424. doi:10.2139/ssrn.2182588
- Kahan, D. (2013b). The value of civic science literacy [Abstract ED32A-08]. Paper presented at the 2013 Fall meeting of the American Geophysical Union, San Francisco, CA.
- Kahan, D. M., Jenkins-Smith, H., & Braman, D. (2011). Cultural cognition of scientific consensus. *Journal of Risk Research, 14*, 147–174. doi:10.1080/13669877.2010.511246
- Kahan, D. M., Jenkins-Smith, H., Tarantola, T., Silva, C. L., & Braman, D. (2015). Geoengineering and climate change polarization: Testing a two-channel model of science communication. *Annals of American Academy of Political & Social Science, 658*, 192–222. doi:10.1177/0002716214559002

- Kahan, D. M., Peters, E., Wittlin, M., Slovic, P., Ouellette, L. L., Braman, D., & Mandel, G. (2012). The polarizing impact of science literacy and numeracy on perceived climate change risks. *Nature Climate Change*, 2, 732–735. doi:10.1038/nclimate1547
- Lewandowsky, S. (2011). Popular consensus: Climate change is set to continue. *Psychological Science*, 22, 460–463. doi:10.1177/0956797611402515
- Lewandowsky, S., Ecker, U. K. H., Seifert, C. M., Schwarz, N., & Cook, J. (2012). Misinformation and its correction: Continued influence and successful debiasing. *Psychological Science in the Public Interest*, 13, 106–131. doi:10.1177/1529100612451018
- Lewandowsky, S., Gignac, G., & Vaughan, S. (2013). The pivotal role of perceived scientific consensus in acceptance of science. *Nature Climate Change*, 3, 399–404. doi:10.1038/nclimate1720
- Libarkin, J. C., Miller, H., & Thomas, S. R. (2013). Scientists' internal models of the greenhouse effect [Abstract]. Paper presented at the 2013 Fall meeting of the American Geophysical Union, San Francisco, CA.
- Lombardi, D., Sinatra, G. M., & Nussbaum, E. M. (2013). Plausibility reappraisals and shifts in middle school students' climate change conceptions. *Learning and Instruction*, 27, 50–62. doi:10.1016/j.learninstruc.2013.03.001
- Lord, C. G., Ross, L., & Lepper, M. R. (1979). Biased assimilation and attitude polarization: The effects of prior theories on subsequently considered evidence. *Journal of Personality and Social Psychology*, 37, 2098–2109. doi:10.1037/0022-3514.37.11.2098
- Maibach, E., Leiserowitz, A., & Gould, R. (2013). A campaign to convey the scientific consensus about human-caused climate change. Paper presented at the 2013 Fall meeting of the American Geophysical Union, San Francisco, CA.
- McCright, A. M., Charters, M., Dentzman, K., & Dietz, T. (this issue). Examining the effectiveness of climate change frames in the face of a climate change denial counter-frame. *Topics in Cognitive Science*, 8, doi:10.1111/tops.12171
- McCright, A. M., & Dunlap, R. E. (2011). The politicization of climate change and polarization in the American public's views of global warming, 2001–2010. *The Sociological Quarterly*, 52(2), 155–194. doi:10.1111/j.1533-8525.2011.01198.x
- Munnich, E. L., Ranney, M. A., & Song, M. (2007). Surprise, surprise: The role of surprising numerical feedback in belief change. In D. S. McNamara & G. Trafton (Eds.), *Proceedings of the Twenty-ninth Annual Conference of the Cognitive Science Society* (pp. 503–508). Mahwah, NJ: Erlbaum.
- Oreskes, N., & Conway, E. M. (2010). *Merchants of doubt: How a handful of scientists obscured the truth on issues from tobacco smoke to global warming*. New York: Bloomsbury.
- Otto, S., & Kaiser, F. G. (2014). Ecological behavior across the lifespan: Why environmentalism increases as people grow older. *Journal of Environmental Psychology*, 40, 331–338. doi:10.1016/j.jenvp.2014.08.004
- Proctor, R. N. (2012). *Golden holocaust: Origins of the cigarette catastrophe and the case for abolition*. Berkeley: University of California Press.
- Ranney, M. A. (2012). Why don't Americans accept evolution as much as people in peer nations do? A theory (Reinforced Theistic Manifest Destiny) and some pertinent evidence. In K. S. Rosengren, S. Brem, E. Evans, & G. M. Sinatra (Eds.), *Evolution challenges: Integrating research and practice in teaching and learning about evolution* (pp. 233–269). Oxford, UK: Oxford University Press.
- Ranney, M. A., Clark, D., Reinholz, D., & Cohen, S. (2012a). Changing global warming beliefs with scientific information: Knowledge, attitudes, and RTMD (Reinforced Theistic Manifest Destiny theory). In N. Miyake, D. Peebles, & R. P. Cooper (Eds.), *Proceedings of the 34th Annual Meeting of the Cognitive Science Society* (pp. 2228–2233). Austin, TX: Cognitive Science Society.
- Ranney, M. A., Clark, D., Reinholz, D., & Cohen, S. (2012b). Improving Americans' modest global warming knowledge in the light of RTMD (Reinforced Theistic Manifest Destiny) theory. In van. Aalst J., K. Thompson, M. M. Jacobson, & P. Reimann (Eds.), *The future of learning: Proceedings of the tenth international conference of the learning sciences* (pp. 2-481–2-482). Sydney, Australia: International Society of the Learning Sciences, Inc.

- Ranney, M. A., Lamprey, L. N., Le, K., & Ranney, R. M. (2013). Climate change cognition: Direct to the public [Abstract]. In M. Knauff, M. Pauen, N. Sebanz, & I. Wachsmuth (Eds.), *Cooperative minds: Social interaction and group dynamics; Proceedings of the 35th Annual Conference of the Cognitive Science Society* (http://cognitivesciencesociety.org/uploads/cogsci13_errata.pdf). Austin, TX: Cognitive Science Society.
- Ranney, M. A., Lamprey, L. N., Reinholz, D., Le, K., Ranney, R. M., & Goldwasser, L. (2013). How global warming works: Climate change's mechanism explained (in under five minutes) [Video file]. In M. A. Ranney & L. N. Lamprey (Eds.), *How global warming works*. Available at <http://www.HowGlobalWarmingWorks.org/in-under-5-minutes.html>. Accessed December 13, 2013.
- Ranney, M. A., Munnich, E. L., & Lamprey, L. N. (in press). Increased wisdom from the ashes of ignorance and surprise: Numerically-driven inferencing, global warming, and other exemplar realms. *The psychology of learning and motivation*. B. Ross (Ed.), New York: Elsevier.
- Ranney, M. A., Rinne, L. F., Yarnall, L., Munnich, E., Miratrix, L., & Schank, P. (2008). Designing and assessing numeracy training for journalists: Toward improving quantitative reasoning among media consumers. In P. A. Kirschner, F. Prins, V. Jonker, & G. Kanselaar (Eds.), *International perspectives in the learning sciences: Proceedings of the 8th international conference for the learning sciences* (pp. 2-246–2-253). Utrecht, The Netherlands: International Society of the Learning Sciences, Inc.
- Ranney, M. A., & Thanukos, A. (2011). Accepting evolution or creation in people, critters, plants, and classrooms: The maelstrom of American cognition about biological change. In R. S. Taylor & M. Ferrari (Eds.), *Epistemology and science education: Understanding the evolution vs. intelligent design controversy* (pp. 143–172). New York: Routledge.
- Richey, S., & Taylor, B. (2012). How representative are Amazon Mechanical Turk workers? Available at <http://themonkeycage.org/2012/12/19/how-representative-are-amazon-mechanical-turk-workers/>. Accessed July 23, 2013.
- Rinne, L., Ranney, M. A., & Lurie, N. (2006). Estimation as a catalyst for numeracy: Micro-interventions that increase the use of numerical information in decision-making. In S. A. Barab, K. E. Hay, & D. T. Hickey (Eds.), *Proceedings of the 7th international conference on learning sciences* (pp. 571–577). Mahwah, NJ: Erlbaum.
- Shepardson, D. P., Niyogi, D., Choi, S., & Charusombat, U. (2011). Students' conceptions about the greenhouse effect, global warming, and climate change. *Climatic Change*, *104*, 481–507. doi:10.1007/s10584-009-9786-9
- Simons, E. (2013). *The secret lives of sports fans: The science of sports obsession*. New York: Overlook Press.
- Stevenson, K. T., Peterson, M. N., Bondell, H. D., Moore, S. E., & Carrier, S. J. (2014). Overcoming skepticism with education: Interacting influences of worldview and climate change knowledge on perceived climate change risk among adolescents. *Climatic Change*, *126*, 293–304. doi:10.1007/s10584-014-1228-7
- Sundblad, E., Biel, A., & Gerling, T. (2007). Cognitive and affective risk judgements related to climate change. *Journal of Environmental Psychology*, *27*, 97–106. doi:10.1016/j.jenvp.2007.01.003
- Tobler, C., Visschers, V. H. M., & Siegrist, M. (2012). Consumers' knowledge about climate change. *Climatic Change*, *114*, 189–209. doi:10.1007/s10584-011-0393-1
- University of Colorado at Boulder (2011). The greenhouse effect. *PhET interactive simulations*. Available at <http://phet.colorado.edu/en/simulation/greenhouse>. Accessed December 28, 2011.

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—i.e., 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 and 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

(continued)

Table . (continued)

Textual Description	Format / Correct Value
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 CO ₂ 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.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

- Appendix S1: Experiment 1's survey items
- Appendix S2: Pencil-and-paper version of the mechanism intervention
- Appendix S3: Mechanism items and coding scheme for responses
- Appendix S4: Experiment 3's additional surprise/embarassment items
- Appendix S5: Experiment 5's curriculum
- Appendix S6: Format of Experiment 6's "representative" NDI intervention
- Appendix S7: Experiment 7's UN Development Programme (UNDP) millennium goals and climate-related funding choices