CO_2 as "Carbon DiLoopy:" Boosting People's Global Warming Acceptance and Concern by Explaining CO_2's Cognitive Effects

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Abstract

The public is united in understanding neither global warming's (GW's) causes nor its urgency. This experiment assesses a novel text (informally called "Carbon DiLoopy") intended to spawn science-normative changes in people's GW beliefs by explaining rising CO_2's negative *cognitive* effects—without mentioning GW or climate change. Thus, it represents an indirect way to increase GW concern. Two control/replication texts explained (a) the carbon cycle and (b) human-caused GW's scientific consensus. All texts, containing roughly 400-words each, were assessed regarding their impacts in changing GW beliefs and attitudes. The carbon-cycle control text yielded expected null results. The scientific-consensus text caused gains in general concern about rising atmospheric CO_2, and—replicating past studies—in GW acceptance and concern. The novel diLoopy text induced gains in all three measured concern/acceptance dimensions: (1) CO_2's effects on *cognition*, (2) rising CO_2 *in general*, and (3) *GW*. We also found *no* evidence of backfire or polarization effects.

Keywords: CO_2 and cognition; global climate change; global warming; carbon dioxide; CO_2 health impacts; belief change; CO_2; science communication; HowGlobalWarmingWorks.org

Introduction

Climate change's ever more profound impacts (IPCC, 2022) threaten humans in many ways. It is crucial, then, that people understand human-caused global warming (GW), climate change's underlying driver, so that they may inhibit it (e.g., Ranney et al., 2012 & 2019). U.S. public understanding of GW, though, and opinion about its seriousness, varies widely (Ballew et al., 2019). A void exists in laypeople's understanding of even GW's *central* physical mechanism (e.g., Ranney & Clark, 2016; Joslyn & Demnitz, 2021). GW-focused news articles often fail to convey crucial facts about the basic climate science mechanisms (Romps & Retzinger, 2019). More rigorous and effective governmental action to combat GW's negative impacts will likely result when public opinions/beliefs better reflect GW's science. Successfully urging people to adopt an alternative understanding or attitude that conflicts with a prior one is not easy, but *is* possible—as when the alternative is novel, surprising, and highly germane (e.g., Ranney et al., 2012). Much progress has been made in fostering such belief revisions. For instance, Ranney and colleagues have developed 12 brief (i.e., about five minutes or less) ways to increase GW acceptance and concern (e.g., ten ways are described in Ranney & Velautham, 2021; Velautham, 2022, describes two more).

The present experiment focuses on a new, indirect, vector for aiding climate change conceptual change: rising CO_2's *cognitive* impairment effects. This contrasts with the typical, direct, *climatological* (i.e., noncognitive) concern: that the large human-caused rise in atmospheric CO_2 (among other greenhouse gases) is causing an extra, not-natural, greenhouse effect. This extra greenhouse effect *is* global warming, which is the main driver of climate change impacts. CO_2 has risen 50% since the industrial age started—up from about 40% a decade ago—and the rise continues.

Our experiment focuses on an under-examined negative effect of higher CO_2: its harm to human thinking abilities. This cognitive effect only recently became a serious scientific concern, so no notable prior research explores how much people might *care* that rising ambient CO_2 can reduce their capacity to think. This experiment focuses on whether people can be made to care (more) about CO_2's cognitive effects—and perhaps enough that such boosted caring might even transfer to caring more about *GW*. This is clearly an empirical question, because one could—alternatively—*just* come to worry about CO_2's effects on one's/society's thinking while *not* changing beliefs/caring about CO_2's *GW* effects.

Consider higher-CO_2's link to impaired thinking. Higher-CO_2 indoor (usually unventilated) air has been shown to yield reductions in mental performance, including reasoning (e.g., Coley, Greeves, & Saxby, 2007; Shendell et al., 2004). Enclosed air has more concentrated CO_2 than outdoor air—largely due to exhaled breaths remaining rather contained (Fisk, Wargocki, & Zhang, 2019; Satish et al., 2012)—and city-dwellers are indoors about 90% of the time (U.S. EPA, 2000). A body of evidence notes CO_2 as a pollutant with direct detrimental impacts on the cognitive functioning of people in schools and offices, where CO_2 is often highest (Fisk et al., 2019; Satish et al., 2012). CO_2 levels in enclosed spaces with inadequate ventilation can result in reduced attention spans and lower test performance (Satish et al., 2012). High CO_2 can cause acidosis in people, causing restlessness, mild hypertension, sleepiness, and confusion (Xu et al., 2011). Even short-term exposure to CO_2 at 800 ppm (parts per million) is linked to Sick Building Syndrome, headaches, dizziness, fatigue—and respiratory tract, eye, nasal and mucous membrane symptoms (Seppänen, Fisk, &

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Mendell, 1999). High CO_2 can reduce decision-making to marginal or even dysfunctional levels (Allen et al., 2016; Satish et al., 2012). Studies find significant, increasing, negative effects of CO_2 at levels between 1000 and 5000 ppm—levels often reached in enclosed spaces with subpar ventilation (e.g., Griffiths & Eftekharib, 2008; Kajtar & Herczeg, 2012; Scully et al., 2019; also see Jacobson, 2010).

CO_2 exposure's harm increases as CO_2 increases (e.g., Jacobson et al., 2019). Satish et al. (2012) found that people in elevated-CO_2 air—even at the 1000 ppm level—for 2.5 hours suffered significant negative effects on their thinking. Likewise, Allen et al. (2016) noted declines in people's activity and their ability to use information when exposed to CO_2 at 1000 ppm, compared to exposure at 500 ppm.

In December, 2022, Earth's atmospheric CO_2 was at 419 ppm, up 50% from the preindustrial 280 ppm (Scripps, 2022), which was already higher than when humans started using fire. This 419 ppm is significantly higher than any level during at least the last 3 million years (which is about tenfold longer than our species' existence), and CO_2 was below 400 ppm during the time that our brains evolved (NASA, 2023). Thus, it is possible that at least some people are already occasionally experiencing CO_2-impaired cognition even when outside. Some outdoor urban areas have reported CO_2 as high as 500 ppm (Satish et al., 2012). By the year 2100, the air's CO_2 concentration could exceed 900 ppm (Collins et al., 2013; cf. the 800 mentioned above), more than tripling the preindustrial concentration. Further, all the studies cited above were *short-duration* experiments; there are no *long-term* exposure data at 400 (or 419 or 900) ppm, so our collective cognition may *already* be subtly suffering. Consider the U.S.'s estimated 2.6-point/person IQ loss attributed to lead (McFarland, Hauer, & Reuben, 2022).

Even if humans can keep outdoor CO_2 below 1000 ppm, that level will undercut efforts to curb indoor CO_2. Reducing indoor CO_2 levels by ventilation with outdoor air requires extra energy (Azuma et al., 2018). Thus, reducing outside CO_2 increases is crucial to inhibiting *indoor* increases, too.

Although CO_2 increases due to fossil-fuel burning may harm human cognition, pilot work indicated that few people see it as a perhaps-impending crisis. Finding a way to inform people of CO_2's cognitive dangers may yield transfer to more acknowledgement, acceptance, and concern about *global warming*'s causes and effects: someone who becomes more worried about CO_2 emissions due to their adverse effects on one's mental health/performance may also come to favor more actions inhibiting climate change—as raised CO_2 is bad for both one's brain *and* Earth's temperature. Such climate-relevant "conceptual bedfellows" are not rare: people often try to save energy just to save money. The new US "controversy" about phasing out gas stoves is another example. Gas stoves produce more greenhouse gases and thus GW than electric stoves, and are bad for one's health—especially in small homes or when people work/sleep near the stove; gas stoves even make NO_X pollutants and often leak methane (Lebel et al., 2022) and carcinogens (e.g., benzene), causing 13% of childhood asthma (Gruenwald et al., 2023).

Recently, Ranney and Velautham (2021) reviewed ways to change minds to nurture greater public fact-based climate-science literacy. When people get clear information about GW's basics (especially when it surprises them), they (a) gain a better climatological understanding, and (b) move their position more toward GW acceptance and further from GW denial (e.g., Ranney, Munnich, & Lamprey, 2016).

Mechanistic explanations help present information in ways that do not devolve into evidentiary claims—so using them supports learners' reasoning (Fernbach et al., 2013). Mechanistic knowledge, especially about GW, is crucial in assessing a specific scientific position's acceptability. Ranney and Clark (2016) indicated that mechanistic accounts (a) help people gain science-normative understandings and attitudes, (b) can "break ties" among debated positions if prior information yielded ambivalence, and (c) are persuasive because they explicate causal relationships (and human-caused GW's scientific mechanism has no alternative causal mechanism to counter it that is even remotely sensical).

Little scientific explanation reaches the public about the mechanism of how climate change comes about (Romps & Retzinger, 2019), yet even brief explanations about GW's mechanism yield a cascade of belief revisions regarding GW knowledge, attitude, and acceptance (e.g., Ranney et al., 2016). Research by Ranney and Clark (2016) and others (e.g., Joslyn & Demnitz, 2021) shows that offering facts about the mechanisms of processes like GW effectively changes the minds of those who may otherwise remain entrenched with opposing beliefs that are disconfirmed by science.

Ranney and Clark (2016) showed that a short (400-word) *text* explaining GW's physical-chemical mechanism yielded gains in GW acceptance/concern—and the effect has been replicated several times (e.g., Joslyn & Demnitz, 2021; Ranney et al., 2019). Such GW gains have also resulted from less-textual modalities such as videos, statistics, and graphs (e.g., Ranney et al., 2019). (E.g., asking people to estimate GW statistics—and then giving them the true values as feedback—*also* increases GW knowledge/acceptance; Ranney & Clark, 2016; Thacker & Sinatra, 2022.) Other work has used *less mechanistic* texts to increase people's GW acceptance and concern: Senthilkumaran, Velautham, and Ranney (2023), successfully used (brief and very-brief) texts about why climate scientists should be trusted. Likewise, one of Velautham, Ranney, and Brow's (2019) conditions provided a text about sea level rise's economic impact. The present experiment also uses a text in its focal conditions as it explains the negative health effects, especially *cognitive* effects, of higher–CO_2 air—including prose explaining some mechanisms causing these effects.

An improved understanding of one scientific process may prompt science-normative changes in other, related, beliefs. For instance, explaining the mechanism of *alternative* (i.e., cognitive) CO_2 risks to people who *deny* GW may lead them to a more *common* understanding of CO_2's risks (i.e., *GW*).

In the present experiment, we assessed whether it is possible to change people's (a) acceptance/concern about GW and (b) concern about human-caused CO_2 emissions—

by providing them with a specific scientific text pertaining to: (1) CO_2's negative impacts on health and certain *cognitive* faculties, and (2) scientific information that atmospheric CO_2 is rising to dangerous concentrations regarding these concerns. We mnemonically call this the "carbon diLoopy" text (in that the O's are two loops and that too much CO_2 makes one feel "loopy").

Precedents exist for *indirectly* boosting GW acceptance (e.g., Velautham et al., 2019). In a salient example, Ranney et al. (2019) showed that GW acknowledgement/concern increases after people get true numeric feedback about estimates *they made* for supra-nationalistic statistics (i.e., statistics that make Americans less nationalistic; e.g., "Where does the U.S. rank for national debt?" ["first"]). "Global warming" was mentioned neither in their nationalism intervention, *nor* in the present diLoopy intervention. (Stemming from Reinforced Theistic Manifest Destiny theory [RTMD; Ranney, 2012], the inverse relationship between nationalism and GW acceptance is bi-causal: increasing participants' GW acceptance conversely causes a drop in nationalism [in various ways; Ranney et al., 2019].)

Along with assessing the novel diLoopy text's efficacy in changing minds about GW and its consequences, we assess the effects of two other texts that serve control, comparative, and/or replicative roles. We thus used three texts: The first text, carbon diLoopy (see Appendix), explains the potentially damaging health impacts of high-CO_2-density air—especially on *cognitive* ability; the *precise* CO_2-cognition link is not yet known, but diLoopy includes mechanistic elements (e.g., that breathing high CO_2-level air can cause acidosis, "leading to symptoms like restlessness, […] hypertension, […] sleepiness, and confusion"). The second text, "carbon cycle," explains how carbon gets in and out of the atmosphere—without mention of GW, climate change, or rising atmospheric CO_2's dangers (other than quite indirectly by noting that burning fossil fuels yields CO_2); this cycle text allows us to assess whether a focused discussion of carbon alone may subtly contribute to greater awareness/concern about emitting it into the air, thus acting as a pure, yet content-relevant, control. The third, "GW scientific consensus," text explains scientists' broad agreement about GW's real threat and the basis of that consensus; this text is inspired by similar texts used effectively in climate science communication studies (e.g., Lewandowsky, Gignac, & Vaughan, 2013; van der Linden et al., 2014), and it is thus a kind of comparative-replicative control condition (i.e., we hoped to replicate the effect *and* we can compare other effects to it). This consensus text has no discussion of CO_2's dangers beyond its climate-change role as a greenhouse gas. This replicative intervention also acts as an experimenter-demand control (cf. diLoopy) to assess whether explaining GW's scientific consensus also impacts one's beliefs about the tangentially-related phenomena of anthropogenic CO_2 release *as a cognitive* health issue.

These texts support three main hypothesis-sets. The first set is that, of the three interventions, the carbon diLoopy text explaining rising atmospheric-CO_2 concentrations' negative *cognitive* impacts will yield (a) the only increase in concern about CO_2's impact on thinking (and the other two texts will not; i.e., a selective effect), (b) increased GW acceptance and concern, and (c) increased *general* concern about rising CO_2. Turning to the consensus text's intervention, we predict that reading about the robust scientific consensus behind human-caused GW will (d) increase GW acceptance-and-concern, (e) increase concern about rising atmospheric CO_2 *generally*, but (f) will *not* lead to increased concern about rising CO_2's impact on *thinking*. Finally turning to the carbon cycle text, we hypothesize that its information will act as a control, yielding no significant gains. (Note: As described below, we designed four conditions; the diLoopy text is used in both posttest-only and pretest-posttest versions to assess between-group changes and the—thankfully, unsupported—prospect of an experimenter demand effect.)

A final hypothesis is that, as Ranney et al. have found (e.g., Ranney & Clark, 2016; Ranney et al., 2019; Velautham et al., 2019) there will *not* be a significant correlation between gains and participants' levels of conservatism. A correlation would suggest a backfire/polarization effect (Lord, Ross, & Lepper, 1979), whereas the lack would again show that conservatives gain from the intervention just as much as liberals do.

Method

Participants

We recruited 714 participants through Amazon's Mechanical Turk (MTurk) service; each had acceptably completed 50 or more (at least minor) MTurk projects ("HITs") with approval ratings over 94% from that work. One was excluded/replaced if (a) one was not from the U.S., (b) one's intervention text "reading-time" seemed super-human, (c) one's response variation on Likert-scale items indicated a non-engaged participant, (d) one's written responses (not analyzed here) were nonsensical/irrelevant, or (e) one failed "softer" (e.g., attention) checks that summed to four or more. After these criteria, 431 participants from the U.S. were retained (and each received only one intervention-text). Participants were 108 +/- 3 per condition; see their by-group assortment below.

Stimuli (Texts)

The three stimulus-texts explained the carbon *cycle* (433 words), the scientific *consensus* on anthropogenic GW (391 words), or the damaging health impacts of elevated CO_2 levels—especially on *cognitive ability* (carbon *diLoopy*, 450 words). Only the consensus text mentions "global warming," "warming," or "climate change" (nine times in all); neither the diLoopy nor cycle texts *ever* uses those three terms. In contrast, the diLoopy text uses "carbon dioxide" (or CO_2) 19 times, while the other two texts use it only once. In further contrast, neither the diLoopy nor consensus texts ever mention "carbon" by itself (i.e., not as part of carbon dioxide or CO_2), whereas the cycle text mentions "carbon" by itself 20 times. Given space constraints, the Appendix includes only the novel diLoopy text; the other two texts are similar to ones available elsewhere. (NB. The consensus text melded

GW prose and numeric information; for related uses of such information see, e.g., Ranney & Clark, 2016, Ranney et al., 2012, Ranney et al., 2019, Ranney & Velautham, 2021, and Thacker & Sinatra, 2022.)

Design and Procedure

Participants gave (IRB-approved) informed consent, agreed to read all materials, and affirmed U.S. residency. They then answered three unrelated items on grammar and arithmetic, to inhibit hypothesis-guessing and aid exclusion efforts (re: attention, etc.). Participants were randomly assigned to one of four groups that differed in their intervention-text and whether a pretest was given. Table 1 shows the experimental design. To focus on between-group contrasts (which are often seen as preferred, given possible sensitivity/demand-effect concerns), only the "sandwiched-diLoopy" condition received both pretest and posttest measures (with the text as "jam" between the tests' "bread"). Its pretest served as a baseline for within-participant gains and (for the other conditions) between-group gains. Thus, *cycle* participants (105 post-exclusions; group 1) had *no* pretest, read the carbon cycle text ("C-Cycle" in Table 1), and received a posttest. C*onsensus* participants (108 post-exclusions; group 2) had *no* pretest, read the scientific consensus text ("GW-Consensus"), and received a posttest. The *open-faced-diLoopy* (as in "open-faced sandwich") condition (107 post-exclusions; group 3) had *no* pretest, read the cognitive impacts of CO_2 text (diLoopy), and received a posttest. The *sandwiched-diLoopy* condition (111 post-exclusions; group 4) *received* this study's *only pretest*, read the cognitive impacts of CO_2 text (diLoopy), and (like the others) received a posttest.

Table 1: Design (with diLoopy = cognitive impairment text)

Group:	1/Cycle (*Open*)	2/Consensus (*Open*)	3/diLoopy (*Open*)	4/diLoopy (*Sandwich*)
Pretest:	-	-	-	yes
Text:	C-Cycle	GW-Consensus	diLoopy	diLoopy
Posttest:	yes	yes	yes	yes

Pretests and posttests contained 20 Likert scale items on 1-7 scales, assessing agreement with statements across three metrics: (1) 12 items (used in many prior studies) addressed *GW* concern, attitudes, and acceptance (e.g., "I am concerned about the effects of human-caused global warming"); (2) five items regarded *general* beliefs and concern about CO_2 increasing in the atmosphere (e.g., "The amount of carbon dioxide (CO_2) in the atmosphere is higher today than 200 years ago"); and (3) three items related to concerns about CO_2 on aspects of *cognitive performance in particular* (e.g., "I am concerned that rising carbon dioxide (CO_2) concentrations will affect my ability to think"). All measures had some negatively-worded items, and those numeric responses were reverse-coded. Several extra items were attention checks.

After the posttest, participants replied to some short-answer queries—with one assessing their text-understanding. Next, they self-rated, on a 1-7 scale, how conservative (both socially and economically) they were. Finally, they wrote (albeit not analyzed herein) about experiences with any study that seemed similar to ours (which might disqualify them).

Results and Discussion

Means were compared across the four conditions and two testing times. Given this experiment's multiple comparisons, we used a Holm-Bonferroni experiment-wise error correction (with alpha = .05); reports herein of significance or non-significance are in keeping with that procedure. We now, in turn, assess each of our three dependent measures' results.

We start with the *thinking-impairment* measure's results. As predicted above, reading about CO_2 harming thinking (diLoopy) changed attitudes and concerns about such impairment: the text about CO_2's dangerous cognitive impacts led to increased concern about how rising CO_2 can impair thinking. The most direct comparison (and our only within-group contrast) is between the pretest and posttest means from the sandwiched-diLoopy condition (with its text about CO_2's cognitive downside)—and for that we see a large gain *from 4.46* (SD = 1.48) *to* 5.66 (SD = 1.35). This +1.20-point gain on the 1–7 Likert scale of *agreement with cognition-related CO_2 concern*, is 47% of the possible gain from the pretest mean and is robustly statistically significant ($t_{(106)} = 10.8$; $p < .00001$). (The open-faced-diLoopy posttest mean was a near-identical 5.63, and *also* robustly significant *from 4.46*, so no apparent experimenter demand was caused by the sandwich group having a pretest; indeed, for the other two measures [addressed below] the open-faced diLoopy means were both numerically *higher*—albeit no more than .1-point higher—than the sandwich means—also indicating no experimenter-demand effects.) As also predicted above, the diLoopy text produced a *selective* cognitive effect in that it was the only text yielding a CO_2-cognition-concern gain; the consensus and cycle groups' cognitive-concern posttests did *not* differ significantly *from 4.46* (posttest *M*'s: 4.64 and 4.66; p's > .3)—and both fell below the diLoopy posttest means (~5.65 for open-faced and sandwiched; p's < .00001).

Turning to the measure assessing *general* CO_2 concern (*not* CO_2's *cognitive* concern), the sandwich-diLoopy group again exhibited a robustly significant pretest-to-posttest increase (i.e., after receiving the condition's *CO_2-reasoning-impacts* text: +0.34; M_{post} = 6.08 [SD =1.10] vs. M_{pre} = 5.74 [SD =1.18]; $t_{(107)} = 5.69$, $p < .00001$). Not surprisingly, given that CO_2 is the most famous greenhouse gas, the scientific-consensus text also significantly increased concern about CO_2 *in general* ($t = 2.93$; $p < .05$)—even though CO_2 is only mentioned once in the consensus text). The carbon-cycle control text, as predicted for all its measures, did *not* produce such a general-CO_2-concern gain ($p > .05$, n.s.); indeed, the cycle text yielded gains on *none* of our measures, showing the carbon-cycle condition's aptness as a content-control. (Again, note that the diLoopy *CO_2-reasoning-impacts* text mentions "carbon dioxide" or "CO_2" 19 times while the consensus and carbon cycle texts each only do so once.)

Let's consider the final measure, regarding *global warming acceptance and concern* (i.e., about GW's most fundamental

and direct aspects); this may be the most practically important of the experiment's three measures. As predicted above, the diLoopy text showed higher acceptance/concern *about global warming*: the sandwich-diLoopy group yet again showed a significant gain (+.27; M_{post}= 5.96 [SD = 1.31] vs. M_{pre}= 5.69 [SD = 1.31]; $t_{(106)} = 4.57$, $p < .00001$). This gain resulted even though the diLoopy text never used "warming," "global warming," or "climate change." Thus, the diLoopy intervention appears to have successfully exhibited transfer-of-training from increased concern about CO_2's *cognitive* effect to increased *GW* concern. This is likely the most societally important of this experiment's three measures' results. Also as predicted (and replicating prior research), the scientific-consensus text with its warming-focused message––and the only text mentioning GW—also yielded a significantly high GW acceptance/concern posttest (to a mean of 6.17; $p < .005$). Posttest GW-concern for the carbon-cycle text, which had neither the diLoopy text's CO_2 focus nor the consensus text's GW focus, was not over baseline, even though "carbon" naturally plays a large role in climate change ($p > .1$, n.s.). Thus, for the GW measure, the carbon-cycle text was indeed a content-control for the other texts.

Finally, the sandwich-diLoopy condition showed that there was *no* significant correlation between size-of-gain and conservatism—for *any* of the three measures, and for *either* economic *or* social conservatism (all $|r|$'s < .141; p's > .1).

General Discussion

This experiment's most important findings stem from the *carbon diLoopy* text (see Appendix). Its factual explanation of potential cognitive/health declines due to rising CO_2 levels in the air increased (a) concern about CO_2-driven cognitive declines, (b) concern about rising CO_2 in general, and (c) even concern and acknowledgement about *global warming* (GW). Perhaps most remarkable is the last part—that diLoopy yielded a transfer effect that increased GW acceptance/concern. That is, although explaining CO_2's cognitive impacts boosted concern about that overtly addressed issue, the text *also* yielded a gain for *GW* acceptance/concern even though GW was *never* mentioned.

Since the diLoopy text focuses only on circumscribed foreseeable effects of people's CO_2 emissions—namely prospective harm to human *thinking* while not even mentioning GW or its consequences—our diLoopy text-intervention shows a notable causal link between concern about rising CO_2's negative mental repercussions and concern about GW. This result coheres with the effects of other interventions that do not directly deal with GW, such as inhibiting nationalism (or providing information about sea level rise), which have been shown to *indirectly* increase GW acceptance (Ranney et al., 2019; Velautham et al., 2019; Velautham & Ranney, 2020). Practically, diLoopy's transfer result indicates that the text may especially act as a persuasive tool to encourage those who mostly do *not* accept climate change's reality (or who even deny it outright) to become more concerned about both the rising CO_2 and *GW itself*—and, even further, to support actions to address both.

This diLoopy-GW transfer effect replicates several prior findings. For instance, in *each* of our three measures, one's gain was uncorrelated with one's level of conservatism. This supports prior work showing that participants' posttest GW acceptance gains are uncorrelated with their conservatism-level (e.g., Ranney & Clark, 2016; Velautham & Ranney, 2020); no backfire/polarization has been observed (van der Linden et al., 2017). This finding has been noted in more than ten prior ways in which brief interventions have been used to increase GW acceptance (e.g., Ranney et al., 2019, Senthilkumaran et al., 2023, and Velautham et al., 2019).

We also replicated (cf. van der Linden et al., 2015) that a scientific-consensus intervention (in this case, an explanatory text) can statistically significantly raise GW concern and acceptance. Furthermore, the carbon-cycle control group, as predicted, showed *no* significant gains; this, combined with various other null results—along with the significant results from the open-faced diLoopy condition—indicates that there was no evidence of experimenter demand (which, in turn, further supports the sandwich-diLoopy gains' validity).

Our text about the negative impact on human thinking abilities caused by CO_2 levels that Earth's air may surpass in coming decades makes the issue of rising CO_2, albeit an unseen and unfelt gas, more personal and immediate. The diLoopy text challenges people with a direct, individual-level, consequence of CO_2 release: cognitive risk. Being able to add concern about rising CO_2 *and* GW, without even mentioning GW, offers a fruitful way to raise climate change concern/acceptance that seems fresh and compelling. The diLoopy text's alarm gives readers a new *alternative* reason both to care about anthropogenic CO_2 releases *and* to support CO_2-limiting actions—without requiring knowledge or even acceptance of GW. Although we hardly recommend prioritizing it in general, for *some* people/contexts, it may even be *easier* to boost concerns about rising atmospheric CO_2's ill effects by explaining these cognitive repercussions than by explaining GW (e.g., its mechanism) itself.

As climatology, cognitive science, and other fields continue to discern the many ways that climate change drastically negatively impacts Earth and its species (e.g., us), it is crucial to continue to develop ways to effectively communicate these impacts to the public. Misinformation and climate change denial are massively detrimental to taking the actions needed to curb global warming; however, changing minds is obviously possible, if not easy—especially when the how's and why's of climate science are made clear.

Limitations/Contextualizations

We note three salient limitations. First, U.S. participants were used because Americans: are numerous, have large carbon footprints, and are more likely to deny GW than people in most peer nations (Capstick et al., 2015; Ranney, 2012). Trans-national follow-up studies (and using multiple, diverse sampling services) would better address representativeness.

Second and more practically, the diLoopy text might be best used in combination with other brief ways that have been shown to boost GW acceptance and concern. (See Ranney &

Velautham, 2021, and Senthilkumaran et al., 2023, for 11 other ways; our lab's HowGlobalWarmingWorks.org public outreach site also offers some). Although the text (see Appendix) yielded a hefty 47% of the possible gain from the pretest baseline for the *CO_2-cognition-concern* measure, that fell to 20% for the *GW-concern* measure (which may be of the most immediate societal importance). Several other interventions have shown a 30%-of-possible (or more) GW gain (e.g., using GW's mechanism, Earth's-temperature graphs, or germane statistics; Ranney et al., 2019)—as did the present study's *consensus* text. Therefore, although the diLoopy text adds value re GW belief revision, if there were time for only one intervention, some others seem superior to it—at least for the *general* public. However, even in isolation, the diLoopy text may be useful for *those who most fervently deny* GW because it provides a strange-bedfellows way to increase concern for CO_2 that is technically unrelated to GW (i.e., cognition-impairing vs. warming-producing). Future research can assess these questions, but strange-bedfellow appeals *are* often useful. After all, many people who are unconcerned about climate change install *solar panels* for non-GW reasons (e.g., lower electricity bills, social signaling, resale value, or electrical-grid independence).

A third limitation regards assessing the diLoopy text's *longevity* in boosting people's GW acceptance/concern—as well as people's (general *or* cognitive) concerns about human-caused-CO_2. No delayed posttest was used, so we do not just assume that noted gains in acceptance and concerns were long-lasting. However, our group's past studies often used similar interventions, and when we assessed participants after a (usually nine-day) delay, the enhanced posttest attitudes—and understandings of the scientific information (e.g, mechanisms or statistics) that had been presented—remained (e.g., Ranney & Clark, 2016; Ranney et al., 2019). These findings also held up with a more extensive intervention (i.e., a longer scientific explanation of GW's mechanics, plus supporting statistics) and a much longer, 34-day, delay before re-testing (Ranney & Clark, 2016).

Conclusions

In essence, this experiment asks the practical question, "Is there a non-climate way to raise concern about GW and rising CO_2 levels?" Our results show that the answer is "yes." In particular, we found that a "carbon diLoopy" text explaining that *rising CO_2 concentrations can harm one's thinking* yielded gains in participants' (1) concern about *those cognitive effects*, (2) concern about *CO_2 in general*, and (3) concern about *global warming*. These results are supported by (a) findings that the effects are *not* due to experimenter demand, (b) a replicative-comparative group using a text about GW's *scientific consensus*, and (c) a null-result control group using a text about the *carbon cycle*. Finally, no backfire/polarization effect was found, as every gain was uncorrelated with conservatism.

With carbon diLoopy, our lab has now shown 12 brief ways by which people's GW acceptance/concern can be increased (Ranney & Velautham, 2021; Velautham, 2022). Some, with various translations, are available at our popular public-outreach site, HowGlobalWarmingWorks.org.

Appendix: Thinking ("DiLoopy") Text

Carbon dioxide (CO_2) is toxic to humans at high concentrations, creating a condition known as hypercapnia, which can result in death. Even at more moderate CO_2 concentrations, studies find that breathing air with elevated CO_2 can have a negative impact on a person's reasoning and mental abilities. There is a growing body of scientific evidence pointing to CO_2 as a pollutant with direct detrimental impacts on the cognitive functioning of humans in schools and offices, where concentrations of CO_2 are often highest.

One study has even argued that modestly elevated concentrations of atmospheric CO_2 can cause acidosis (more acidic blood) in humans, leading to symptoms like restlessness and mild hypertension, and eventually sleepiness and confusion. Another study has found that elevated CO_2 can cause people's decision-making performance to fall to scores considered marginal and even dysfunctional.

Studies find that the negative impacts of CO_2 exposure increase in severity as the concentration of CO_2 increases in the atmosphere. CO_2 levels are typically higher in enclosed spaces with insufficient ventilation, and this can result in a reduced attention span and a lower test performance. Current atmospheric CO_2 levels are about 410 parts per million (ppm), up from a preindustrial value of 280 ppm, and this number is constantly increasing, primarily due to the burning of fossil fuels (coal, oil, and gas). By the end of the century, the atmospheric CO_2 concentration could be as high as 1,000 ppm, making it impossible to get a "breath of fresh air."

Within enclosed spaces, CO_2 is even more concentrated than it is in the atmosphere because the exhaled gas from breathing contributes to the concentration. This is especially worrying as city-dwellers spend approximately 90% of their days indoors. According to one study, "atmospheric carbon dioxide concentrations are reaching levels never experienced by Homo sapiens" and "future carbon emissions will increase indoor concentrations to levels harmful to human cognition."

According to the National Oceanic and Atmospheric Administration, "Human activities have a tremendous impact on the carbon cycle. Burning fossil fuels, changing land use, and using limestone to make concrete all transfer significant quantities of carbon into the atmosphere. As a result, the amount of carbon dioxide in the atmosphere is rapidly rising; it is already considerably greater than at any time in the last 800,000 years." Scientists warn that if humans continue emitting CO_2 into the atmosphere at current rates, it will become increasingly difficult to manage the negative health and mental effects of elevated CO_2.

It is possible that, as CO_2 levels continue to increase, the diminishment of human cognitive abilities will also become more pronounced. One study concludes that the best way to prevent this hidden consequence of increasing atmospheric CO_2 is to reduce fossil-fuel emissions.

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