Promoting Climate Actions: Applying a cognitive constraints approach

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Abstract

The present paper reports an experiment ($N = 348$) with a two-year-delayed (M = 695 days) follow-up that tests an approach to raising willingness to take climate actions. Here we focus on the longitudinal results. Our experimental materials were designed to harness the power of two cognitive constraints — coherence and causal invariance, which map onto two narrative proclivities that anthropologists have identified as universal — to promote climate action across the political spectrum. Towards that goal, the essential role of these constraints in belief formation predicts that climate-change information would be more persuasive when it is embedded in a personal climate-action narrative, the evocation of which can benefit from exposure to parsimonious scientific explanations of indisputable everyday observations, juxtaposed with reasoners' own, typically less coherent explanations, occurring in a context that engages their moral stance. Our brief one-time intervention, conducted in U.S. states with the highest level of climate skepticism, showed that across the political spectrum, our materials raised willingness to take climate actions in the immediate assessment. It also raised the likelihood of reports two years later of having taken or would have taken those actions had the opportunity existed, suggesting long-lasting effects. Our approach adopts the framework that conceptions of reality are representations, and adaptive solutions in that infinite space of representations require cognitive constraints to narrow the search.

Keywords: belief revision; coherence; causal invariance; climate change; science communication

Introduction

Before the advent of our currently divided world, some had thought that a helpful step towards telling truth from falsehood was to check the trustworthiness of an information source. That step no longer serves its function for both sides of the divide, now that the two sides trust divergent sources that do not share the same "facts" (Jurkowitz et al., 2020; Mitchell et al., 2014). In part due to pervasive disinformation on climate change, conveying to the public the scientific evidence for *anthropogenic climate change* (ACC) and the impending catastrophe has not resulted in sufficient understanding of the urgency for climate action. "Clearly, I haven't gotten this message across," lamented NASA astrophysicist James Hansen (2012). Recognizing the world's failure to act despite urgent calls by climate scientists and activists, he pleaded for help.

The present paper suggests an answer to his plea based on work in cognitive science. A challenge for communicating climate science is that those unwilling to take climate action may not respond to scientific evidence supporting ACC. A survey by the Pew Research Center (Funk & Kennedy, 2020) observed that "Partisanship is a stronger factor in people's beliefs about climate change than is their level of knowledge and understanding about science." The survey found that Republicans were unlikely to believe in ACC, and their position did not change with higher science knowledge. Other studies (Drummond & Fischhoff, 2017; Kahan et al., 2012) have found that those with the highest science literacy and technical reasoning capacity in fact showed the greatest polarization on climate-risk perception.

Previous studies have demonstrated progress towards increasing acceptance of ACC. Consistent with observed correlations between climate knowledge and acceptance of ACC (e.g., Stevenson et al., 2014), Ranney et al. (2012), Ranney and Clark (2016), and Arnold et al. (2015) found that teaching the mechanism of global warming dramatically increased acceptance of ACC and pro-environment attitudes across the political spectrum, an effect that continued to hold when tested as many as 34 days later. Others have shown that emphasizing the broad consensus on ACC among climate scientists also led to higher acceptance of ACC (Lewandowsky et al., 2013). However, there has not been any study, to our knowledge, that measures whether 1) an intervention leads to improved odds of taking climate actions, and 2) the resulting improvement is sustained over a substantially longer interval.

In this paper, we ask: Given that neither perceived authority nor consensus within a society or circle is a measure of truth, can principles basic to cognition be recruited to promote sustained climate actions? To show that cognitive constraints operate pervasively, including on conservatives, we conducted an experiment testing our approach in ten U.S. states that scored lowest in ACC beliefs (Howe et al., 2015). Here we focus on results from participants who returned for the follow-up. See Lee et al. (2023) for a full report of the results.

The Mind's Representation-dependent Reality and Cognitive Constraints

Cognitive science shows that human understandings of reality are representations of it (e.g., Hawking & Mlodinow, 2010; Hoffman, 2019; Hume, 1739/1987; Kant, 1781/1965). Percepts and beliefs are therefore the result of a search in an

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infinite space of possible representations (e.g., Kant, 1781/1965; Pizlo, 2001). This pervasive problem of *under-determination* is no longer an abstract insight confined to philosophy but an integral part of current vision science (Li & Pizlo, 2011), engineering (Jayadevan et al., 2017), and clinical treatment (Ramachandran & Hirstein, 1998; Botvinick & Cohen, 1998).

Take perceiving a cube as an example. The 2-dimensional image cast by a cube on our retina is ambiguous, in that it can map onto an infinite number of 3-dimensional objects — objects that need not be symmetric, and the edges of which do not have to be straight lines (e.g., Pizlo, 2001). But despite the inherent under-determination of the distal object, we are not paralyzed by indecision: we perceive a cube. Narrowing down to this adaptive percept within the infinite space of possible distal objects illustrates the application of potent constraints in the form of *a priori* assumptions — in this case, the default assumption that the distal object has the simplest form that is consistent with the image; in other words, a cube as the object provides a "*parsimonious explanation*" of the image. To analogously avoid paralysis, an adaptive solution for constructing causal beliefs requires cognitive constraints (Marr, 1982).

Two central constraints that operate hand-in-hand address the challenge of forming generalizable causal knowledge in that immense space of possibilities. One is the coherence of causal explanations (Thagard, 1989). Diverse fields have converged in showing that scientists and untutored reasoners alike seek *coherent explanations*, and prefer more *parsimonious* ones: logically consistent explanations with fewer assumptions. Mathematical derivations show that parsimonious explanations yield the most efficient path to truth (Kelly, 2007). Evidence for the constraint abounds in the history and philosophy of science (Kuhn, 1962/2012; Newton, 1687/1727; Thagard, 2000), experimental psychology (e.g., Lombrozo, 2016), and anthropology (Ochs & Capps, 2001).

Two principles from Thagard's (1989) theory of *explanatory coherence* — Explanation and Contradiction — make explicit how we characterize coherence. His *Explanation* principle concerning a set of propositions, P, states, If P explain Q, then: (a) Each proposition in the set coheres with Q, (b) Any pair of propositions in the set cohere, and (c) In (a) and (b), the degree of coherence is inversely proportional to the number of propositions in the set. Thagard regards this principle to be "by far the most important for assessing explanatory coherence" (p. 437). His *Contradiction* principle states: "If P contradicts Q, then P and Q incohere" (p. 437). Following Thagard, our use of "logical inconsistency" covers both syntactic and semantic contradictions. We treat observations as propositions. Thus, the belief that "there is one high tide a day at the Santa Monica Pier" is logically inconsistent with the observation that "there are two high tides a day at the Santa Monica Pier".

A second cognitive constraint is *causal invariance*: Deviation from causal invariance provides a critical signal for a need for belief revision (e.g., Bye et al., 2023; Cheng, 1997; Cheng et al., 2022; Rescorla & Wagner, 1972; Woodward, 2000, 2005; for explications of the constraint, see Ichien & Cheng, 2022; Park et al., 2022). This constraint arises from a (tacit) goal to acquire useable/generalizable causal knowledge, "useable" in the sense that the knowledge is causally invariant across the learning and application contexts. It implies that when reasoners experience a deviation of the observed outcome from that predicted by the application of their causal explanation of a phenomenon to a new situation, that deviation signals a need to revise the explanation. The goal is to formulate an explanation that consistently holds across both the old and new contexts, so that the previously deviating observation can be accommodated under the updated set of assumptions.

Strikingly, these two constraints — identified under a cognitive-science analysis of the problem of under-determination — map onto two universal proclivities that anthropologists Ochs and Capps (2001) have identified across everyday narratives in diverse cultures around the globe: a deep-rooted yearning to construct 1) a coherent account of life events and 2) an accurate, authentic account, noting deviations from what would fit the attempted coherent explanation.

Like scientific theories, narratives are explanations. Bruner (1991) proposed that scientific theories are to narratives as explanations of phenomena are to explanations of the unfolding of human-related events or situations. Ocean tides occurring every day is a phenomenon, explained by Newton's law of universal gravitation. Narratives are the other type of explanation, notably issuing from a point of view that carries specific values and aims. Actions, the target outcome of our study, are explained by one's values and aims. Narratives are never "point-of-viewless," notes Bruner (p. 3). For the same reason, voluntary action is never point-of-viewless.

Similarly, Ochs and Capps (2001) observe that accounts of life events all adopt a perspective, and central to the perspective is its *moral stance*, "a disposition towards what is good or valuable and how one ought to live in the world" (p. 45). In line with the anthropologists' observations, psychologists have argued that values are critical for effective science communication (Kahan, 2010; Medin & Bang, 2014).

Why do people around the globe have the same two narrative proclivities? In our view, the representation-dependent realism framework provides an explanation: These deep-rooted yearnings are implementations of the corresponding constraints that enable cognition itself. The need to avoid cognitive paralysis explains the need for coherent narratives. In return, findings on the universality of the yearnings provide evidence for the breadth of scope of the cognitive constraints, manifesting as they do in personal explanations of life events and of one's place in the world.

Applying Cognitive Constraints

To persuade people to take climate actions, our study sought to foster the construction of a coherent climate-action narrative. The critical role of coherence and causal invariance in cognition suggests that to effectively change beliefs, an intervention should take these steps: 1) elicit reasoners' causal explanation of a phenomenon based on their prior beliefs, 2) provide information that enables them to notice inconsistencies between the prediction based on their explanation and actual observations (steps 1 and 2 together evoking the causal-invariance constraint), and 3) provide a more coherent explanation as a replacement (evoking the coherence constraint). At the level of individual exercises in the science components of our intervention, we implemented these three steps, to be illustrated presently. At the more abstract level of the choice of topics to include in our materials, we aimed at providing essential building blocks for constructing a coherent climate-action narrative. Informed by anthropologists' findings on the human need for coherent and authentic narratives to account for life events (Ochs & Capps, 2001), we propose that three such components are:

1) an understanding that climate change is anthropogenic,
2) an appreciation of science in general, and resonance with the parsimony of scientific explanations in particular, and
3) a conception of the self as someone morally responsible for the consequences of climate change.

The purpose of these components was to serve as building blocks for participants to create or revise their own climate-action narrative. If one or more of the components are previously missing in some participants' belief system, our intervention would raise willingness to take climate actions.

The first component concerns scientific evidence for ACC, because ACC as explained and predicted by climate-science models (e.g., IPCC, 2018) is the raison d'être for climate action. Without some knowledge of scientific evidence for ACC, a climate-action narrative would be missing a crucial cause-and-effect link.

The second component consists of exercises with questions about indisputable relatable phenomena explained by science, with an emphasis on the parsimony of the explanations as defined by the Explanation and Contradiction principles in Thagard's (1989) theory.

The third component sought to evoke moral values that would explain and motivate caring action. This component centered on a question asking how participants would like a psychotherapist (who spoke in the interview excerpted in the question) to counsel farmers who have become suicidal from losing their livelihood after historic floods in the Midwest (Rosmann & Atkin, 2019). Many alternative candidates may serve the same role (e.g., species in danger of extinction due to climate change), while others may not. Victims of mass shooting, for example, would evoke empathy but would not enable a coherent climate-action narrative.

If participants do connect the dots across the components, the climate-action narrative they implicitly construct might be something like this: "I saw that an extreme drought in the Midwest devastated farmers and their families. These folks didn't cause the drought any more than I did. Climate scientists explain the more frequent occurrence of once-in-a-lifetime droughts, floods, and wildfires by humans' burning of fossil fuel since industrialization. If I hadn't come across the scientists' explanation, I would never have thought that my plane trips or the cheeses I enjoy had *anything* to do with crops failing disastrously or houses being washed away in distant lands. My actions affecting greenhouse-gas emissions, especially those contributing to large-scale public policies, can mitigate suffering brought by climate change."

A Test of the Cognitive-Constraints Hypothesis

Experimental Design

Table 1 summarizes the six conditions in our experiment testing the cognitive-constraint hypothesis. The *Full-coherence* condition consisted of three components: 1) the moral-identity/suicidal-farmers question, 2) a set of seven *general-science-prediction exercises*, and 3) a *climate-science-prediction exercise*. Five other between-subject conditions omitted one or more of the three components of the intervention materials to form two 2 x 2 designs, each of which independently varied one component and its complementary components. The Full-coherence and Control conditions were in both designs; their sample sizes therefore approximately doubled those of the others.

All conditions ended with a survey that included questions on willingness to take various climate-mitigating and pro-environment moral actions, science-fact knowledge (Kennedy & Hefferon, 2019), and demographic information (age, gender, educational level, political identity). Participants answered whether they were willing to take thirteen moral actions related to climate change or the environment. Due to space limitations, here we focus on the two political climate questions: 1) Participate in a climate-action demonstration, and 2) Vote for legislatures that promote policies that help create a more sustainable planet. Other climate actions show a similar pattern of results (see Lee et al., 2023).

Because the components collectively enable the connecting between them, they should have non-additive effects if a substantial proportion of the sampled population is missing all three components.

All of our study's materials, data, and code for analyses can be found at https://osf.io/4j738/.

Table 1: Component materials in each of six experimental conditions.

Condition	Moral- identity /farmers	General-science prediction	Climate-science prediction	Assessment survey
a) Full coherence	√	√	√	√
b) All but moral-identity		√	√	√
c) Moral-identity only	√			√
d) All but climate-science	√	√		√
e) Climate-science only			√	√
f) Control				√

Participants

The participants were 348 adults aged 18 years or older (198 females, 3 non-binary gender, M_{age} = 38.3, SD_{age} = 12.6) who were recruited through Amazon Mechanical Turk from December 2019 to January 2020 (*Phase 1*). The UCLA Institutional Review Board approved the procedures of the experiment. All participants provided informed consent. They were randomly assigned to one of the six conditions in Table 1.

To have maximal access to conservative participants on MTurk, we recruited from only the ten U.S. states that scored lowest in the belief that climate change is human-caused (Howe et al., 2015): Wyoming, West Virginia, Alabama, Oklahoma, Idaho, Arkansas, Kentucky, North Dakota, Louisiana, and Utah. For more information regarding the exclusion criteria for Phase 1, see Lee et al. (2023).

Between November 2021 and December 2021 (*Phase 2*), all participants who indicated interest in a "3- to 5-minute follow-up study" (N = 224) were invited to return. Eighty-eight returned (39% of those invited). All return participants were included in our analyses.

Materials

Below we illustrate how our general science exercises were designed to engage the two cognitive constraints. These exercises presented questions about events that laypeople could observe or verify in their own lives, such as water shooting out of a garden hose, or ocean tides that they could experience or look up in a tide chart.

In the *garden hose exercise*, participants were shown a diagram of a coiled hose placed flat on the ground. They were asked to predict the path of the water as it leaves the hose (McCloskey & Kohl, 1983).

For feedback, a video showed water shooting out in a straight line from a horizontally coiled garden hose. Participants whose prediction — based on applying their prior causal model of forces to the situation — deviates from the observed phenomenon would be motivated to revise their causal model (note implementation of the causal invariance constraint). A short paragraph explained the phenomenon by Newton's First Law of Motion, which states that an object continues its motion with its velocity unchanged *unless* an external force acts on it (predicting that once the water is not confined within the hose, it would continue moving in the same direction in a straight line). This law is a more coherent explanation of the water's trajectory in two ways: 1) its prediction is consistent with the observed outcome, and 2) it explains both celestial and terrestrial motion.

Explication of the latter straddles the garden hose exercise and the ocean tides exercise. The *ocean tides exercise* stated, "Gravitational force from the moon causes tides in coastal areas. How many high tides and low tides do you think a coastal area experiences a day?" A reminder stated that Earth makes one complete rotation on its axis every 24 hours.

The feedback stated that there are two 2 high tides and 2 low tides a day, and explained the phenomenon in terms of Newton's law of universal gravitation. The explanation brought attention to this law's prediction that the moon's pull operates *everywhere* on Earth, not only on the oceans. The exercise continued, "By the way, what if the same natural force that causes the tides were to stop? What path do you think our moon would take? (Recall how water shoots straight out once its path isn't forced to curve inside the garden hose.)" The reminder brought attention to the broad scope of Newton's First Law.

The feedback continued, "Earth's massive pull on the moon is what keeps it from flying off, causes it to curve its path, keeping it in orbit, close to Earth as we see crossing our night sky every night." Showing that Newton's law of universal gravitation explains ocean tides as well as the moon's orbit brings further attention to the universality– hence parsimony – of these laws.

Participants typically could not explain the surprising high tide on the side of Earth away from the moon. To predict that other high tide, their intuitive — less parsimonious — explanation would require assuming an exception condition or the presence of an extra celestial body orbiting in sync with the moon but on the opposite side of the Earth.

The Full-coherence questions/exercises in total, without the dependent measures, took a median of 32.0 minutes. The climate science exercises similarly implemented the two cognitive constraints. (See Lee et al., 2023, for a full report of our materials.)

At the end of Phase 1, participants were asked to indicate their willingness to take each of thirteen moral actions. In the follow-up session, the opening instruction asked, using the same positive wording as before, "In the past two years, which actions have you taken to protect and support the flourishing of our planet?" They were probed about the same thirteen moral actions. Because taking an action may not have been an option, participants were first asked whether they have had opportunities to take the action in the intervening time. If they answered "yes", they were further asked whether they have taken the action. Otherwise, they were further asked whether they *would have* taken the action if they could. The first branch of the conditional question measures having taken the action in the interim two years. The second branch is a measure of sustained willingness to take the action.

Results from the Follow-Up Assessment

Return participants in the All-but-moral-identity, Moral-identity only, All-but-climate-prediction, and Climate-prediction only conditions—the *Partial-coherence conditions*— are pooled because their sample sizes are unfortunately too small for meaningful 2 x 2 analyses analogous to those conducted for our Phase 1 data.

The average between-phase interval was about 99 weeks for the Full-coherence condition (M_F = 693.5 days, SD_F = 18.7), Partial conditions (M_P = 695.6 days, SD_P = 13.3), and Control Condition (M_C = 696.9 days, SD_C = 16.2).

In the following four subsections, we report a series of ordinal logistic regressions controlling for three covariates: political identity, education level, and science knowledge. The first two subsections examine return participants' climate action responses in Phase 1 and Phase 2, respectively, comparing across conditions for each phase. Our cognitive constraints hypothesis predicts that, compared to participants in the Partial and Control conditions, those in the Full-coherence condition would be more willing to take climate actions, and hence more likely to report having taken those actions. Accordingly, all pairwise comparisons between the Full-coherence condition and other conditions will report one-tailed *p*-values. The third subsection assesses the predictiveness of a participant's willingness to act in Phase 1 for reports of having (or would have) acted in Phase 2. A fourth subsection examines whether return participants show a self-selection bias that could explain the findings on political climate actions. It compares the Phase 1 willingness responses of return participants to those who did not return.

Return Participants' Phase 1 Willingness Response

To examine whether the subset of participants who returned resembles the whole sample, we first compare the three groups of participants on their willingness responses in Phase 1. Our Phase 1 results (reported in Lee et al., 2023) show that Full-coherence condition led to the greatest willingness to take climate actions, and that the effect cannot be explained by additive effects from the constituent components. Fig. 1 shows the estimated probabilities of selecting 0, 1, or 2 political actions for the return participants. In both Figs. 1 and 2, the unmarked distance above each bar indicates the estimated probability of selecting zero action. Consistent with the pattern of results in Phase 1, return participants in the Full-coherence condition indicated willingness to take a greater number of political climate actions compared to those in the Partial conditions, $OR_{F,P}$ = 3.25, p = .015, and the Control condition, $OR_{F,C}$ = 3.02, p = .027. Participants in the Partial conditions did not indicate greater willingness to act relative to those in the Control condition, $OR_{P,C}$ = 0.93, p = .45. Notably, for the return participants as for the whole sample, there was no indication that our Full-coherence condition was any less effective for conservatives than for liberals (see Fig. 1). If anything, the effect was larger for conservatives. In a separate likelihood ratio test of cumulative link models (Christensen, 2019), we compared the above logistic model with one that included an interaction between condition and political identity; that non-directional analysis does not show evidence for an interaction between condition and political identity, $\chi^2(2) = 3.22$, p = .20. This pattern of results suggests that the subset of participants who returned was indeed representative.

The effectiveness of the various conditions cannot be explained by the number of questions in the condition or the amount of time spent. For example, although the moral-identity/farmers question by itself, which took a median of 7.2 minutes, had no effect on willingness to take climate actions, omitting it from the full-coherence condition reduced such willingness by as much as omitting all eight science-prediction exercises, which took a median of 24.8 minutes.

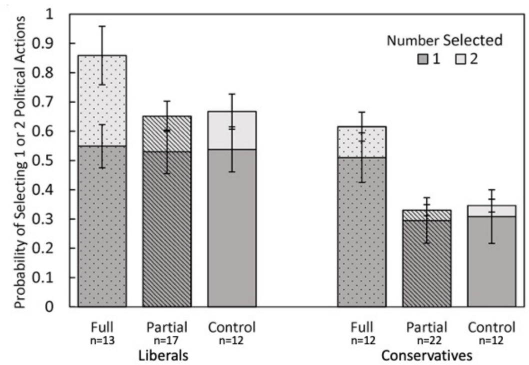

Figure 1: Estimated probabilities of selecting 0, 1, or 2 political climate actions across experimental conditions and political identities (self-reported liberals vs. conservatives) at the end of Phase 1 among participants who returned. To obtain these values, an ordinal regression was conducted with political identity, level of science-fact knowledge (0, 1, 2, 3), and education level (high school diploma or below, college degree, and postgraduate) as covariates.

Phase 2 Reports of Taking Climate Actions

To assess whether our brief online intervention affected (reported) behavior during the close-to-two-years between phases, the following ordinal logistic regression compares return participants on their responses in Phase 2. The outcome of interest throughout this section is whether participants reported having taken/would have taken the action had the opportunity existed. Most return participants (81%) reported they had the opportunity to "vote for political candidates who advocate policies that help create a more sustainable planet, such as drastically phasing out fossil fuel," but few (8%) reported they had the opportunity to participate in a climate-action demonstration, likely due to the Covid-19 pandemic. The analyses and predictions are analogous to those in the preceding section.

Strongly corroborating the validity of the willingness measure in Phase 1, and in further support of the cognitive-constraints hypothesis, return participants in the Full-coherence condition were more likely to report having taken/would have taken additional political climate actions compared to those in the Control condition, $OR_{F,C}$ = 2.95, p = .035, but those in the Partial conditions did not, $OR_{P,C}$ = 1.74, p = .167. However, the Full-coherence return participants were not more likely to report taking more of these actions compared to those in the Partial conditions, $OR_{F,P}$ = 1.70, p = .15. As before, the differences between conditions show a similar pattern across conservatives and liberals, with conservatives showing a clearer effect (see Fig. 2). A separate likelihood ratio test of cumulative link models does not show a significant interaction between condition and political identity, $\chi^2(2) = 3.11$, p = .21.

The Partial participants' responses were descriptively higher in Phase 2 (Fig. 2) than Phase 1 (Fig. 1), possibly because once those who previously lacked an essential component were provided with that component in Phase 1, they would have had fewer missing components to fill in on their own during the two-year interim.

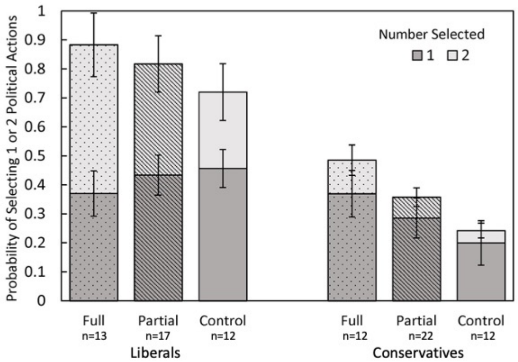

Figure 2: Estimated probabilities of selecting 0, 1, or 2 political climate actions across experimental conditions and political identities (self-reported liberals vs. conservatives) at the end of Phase 2 among participants who returned, controlling for the same covariates as in Figure 1.

Predictiveness of Willingness Responses in Phase 1

The following analysis examines how well participants' Phase 2 reports of taking a political climate action are predicted using their willingness responses from Phase 1 as the primary predictor. Specifically, the to-be-predicted outcome is whether a participant reported having taken an action/would have taken the action if they had the opportunity.

The more political climate actions participants responded they were willing to take in Phase 1, the more likely they were to report a greater number of these actions they have actually (or would have) followed through two years later, $OR = 4.46$, $p < .001$ (two-tailed, because we do not have an *a priori* hypothesis on the predictiveness).

The high predictiveness of the willingness responses in Phase 1 for the climate action responses in Phase 2 validates both our willingness-to-act and report-of-action measures. More specifically, it corroborates our findings on the effectiveness of our intervention in promoting climate action. Participants' willingness-to-act responses or their reports of having taken or would have taken an action do not imply actual actions. However, consistent and orderly differences in these measures across conditions should nonetheless reflect degrees of likelihood to take the actions.

Assessing Self-Selection Bias

It is possible that our interventions caused participants who were more concerned with ACC to return, rather than influenced them in the ways suggested by their responses at face value. To rule out that possibility, we compare the Phase 1 willingness responses of the return participants to those of participants who did not return.

There was no evidence for a self-selection bias in any of the conditions. Within the Full-coherence condition, return participants indicated being willing to take a similar number ($M_R = 1.00$) of political climate actions as those who did not return ($M_{NR} = 0.97$), $OR_{R,NR} = 1.26$, $p = .62$. Likewise, there was likewise no indication of a difference in the number of political climate actions that return participants within the Partial conditions indicated they were willing to take ($M_R = 0.33$) compared to those who did not return ($M_{NR} = 0.63$), $OR_{R,NR} = 0.68$, $p = .33$, or within the Control condition, ($M_R = 0.50$) versus ($M_{NR} = 0.56$), $OR_{R,NR} = 0.71$, $p = .48$.

Discussion

Our analyses indicate that our brief one-time online Full-coherence intervention, compared to the Control condition, not only raised participants' willingness to take more political climate actions in the immediate assessment, but likely also led them to take such actions during the interim two years. Our findings show that climate-change persuasion can be effective when educational materials leverage two basic cognitive constraints—causal invariance and coherence. Specifically, for both conservatives and liberals, embedding ACC information in materials on 1) incontrovertible everyday observations for which science gives explanations that are recognized as more coherent than a reasoner's own, and 2) victims suffering from a weather catastrophe that can be coherently explained by ACC, raised both willingness and likelihood to take climate actions, compared to presenting ACC information alone. This pattern of results is to be expected if these constraints enable cognition itself and operate across all humanity.

It is rare for belief-revision interventions to have an effect that lasts for more than several weeks or months. For example, Horne et al.'s (2015) intervention on vaccine skeptics that emphasized the risks of not vaccinating showed a significant immediate effect, but in a successful replication study, the effect was unclear after one week; and Maertens et al. (2020), in their successful replication of the effect of messaging scientists' consensus on ACC (Lewandowsky, et al., 2013), found that the effect shows partial decay after one week. All of these interventions involved confronting entrenched countervailing societal or personal narratives; none involved harnessing cognitive constraints to foster a competing narrative. Some evidence suggests that invoking the causal-invariance constraint [e.g., asking participants to explain their (typically wrong) answer before providing feedback] is a factor that differentiates between interventions that led to a sustained change in ACC beliefs (Arnold et al., 2013; Ranney et al., 2012) and an otherwise identical intervention that did not (Schotsch & Powell, 2022). Furthermore, these lines of research differed in whether moral identity was evoked (see Lee et al., 2023).

Our study's exceptionally long-lasting effect on promoting climate actions speaks to the fundamental role in belief formation played by the coherence and causal invariance constraints, a role that follows from the view that belief formation occurs as a search in an infinite space of possible representations of reality, and cognitive constraints are essential for enabling the possibility of solutions. Our approach is no doubt only one among many potential others to effectively promote climate actions by making use of cognitive science.

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