1 **Quantifying the Impact of Skeptical Science Rebuttals in Reducing**
2 **Climate Misperceptions**

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9 **Abstract.** Misinformation about climate change causes societal damage in a number of ways and consequently, resources are
10 required to support interventions that counter their influence. Aiming to meet this need, Skeptical Science is a highly-visited
11 website featuring 250 rebuttals of misinformation about climate change. The rebuttals are written at multiple levels—basic,
12 intermediate, and advanced—in order to reach as wide an audience as possible. This study collects survey data from visitors to the
13 website, measuring their belief in climate facts and myths before and after reading a rebuttal. Our data found that a plurality of
14 visitors were already highly convinced regarding climate facts, indicating many visitors come to the site not to answer unresolved
15 questions but to gather resources and answers. We found that the rebuttals were effective in reducing belief in climate myths but
16 that some rebuttals show a concerning reduction in belief in climate facts. The greatest improvement occurred with visitors who
17 began with the most inaccurate climate perceptions. This indicates that the website is useful for two main audiences - those who
18 are convinced about climate change but looking for material to support their own climate communication efforts, and those who
19 disagree with climate facts but are open to new information. We examine potential ways that Skeptical Science rebuttals could be
20 updated to improve their performance in raising climate literacy and critical thinking skills.

21 **1 Introduction**

22 Despite the overwhelming scientific consensus on human-caused climate change (Cook et al., 2013; Cook et al., 2016), there is
23 still public confusion over the severity of climate change and therefore insufficient public demand for climate action. A significant
24 contributor to this lack of progress is climate misinformation, which damages society in a number of ways. The obvious impact of
25 climate misinformation is the instilling of false beliefs or lowering of accurate beliefs, with even just a few misleading statistics
26 reducing people's climate perceptions (Ranney & Clark, 2016). However, climate misinformation has more subtle and subversive
27 impacts. It polarizes the public, having a disproportionate impact on political conservatives such that after being exposed to
28 misinformation, people with different political backgrounds end up further from each other in their climate perceptions (Cook et
29 al., 2017).

30 When scientists get attacked, it can influence them to downplay how they report their scientific results, lest they appear to resemble
31 the stereotype attacks made about them (Lewandowsky et al., 2015). This chilling effect extends beyond the scientific community,
32 with the general public less likely to talk about climate change with friends and family, largely because of fear of pushback (Geiger
33 & Swim, 2016). One particularly subversive impact of misinformation is that when people are confronted with conflicting pieces
34 of information (e.g., facts and misinformation) and have no way to resolve the conflict, they tend to disengage and believe neither
35 (McCright et al., 2016; van der Linden et al., 2017; Vraga et al., 2020). This impact is highly consequential for educators, scientists,
36 and communicators, as it means that any efforts to communicate facts can be cancelled out by misinformation.

37   Climate misinformation in the form of conspiracy theories also causes damage spilling beyond the issue of climate change. One
38   study found that when people were exposed to a conspiracy theory about global warming, they were less likely to sign a petition
39   in support of measures to reduce global warming and less likely to donate to a charity (van der Linden, 2015). Conspiracy theories
40   also increase people's feelings of powerlessness, uncertainty, and disillusionment, which reduces their intention to engage in
41   politics more broadly (Jolley & Douglas, 2014). This myriad of negative impacts necessitates the need to develop resources and
42   interventions to counter climate misinformation.

43   Much psychological research has been conducted into effective ways to refute misinformation. One strategy is to dislodge myths
44   with a "replacement fact" that possesses at least the same explanatory relevance as the myth (Ecker et al., 2010; Seifert, 2002).
45   However, factual information alone may not be enough as when people are presented with both facts and myth countering the fact,
46   the two can cancel each other out (McCright et al., 2016; van der Linden et al., 2017; Vraga et al., 2020). This risk can be mitigated
47   by explaining the misleading rhetorical techniques or logical fallacies used by the misinformation to cast doubt on the facts (Cook
48   et al., 2017a). These disparate strategies have been synthesised in the Debunking Handbook 2020 which suggests that debunkings
49   should adopt a fact-myth-fallacy-fact structure (Lewandowsky et al., 2020).

1.1 Skeptical Science

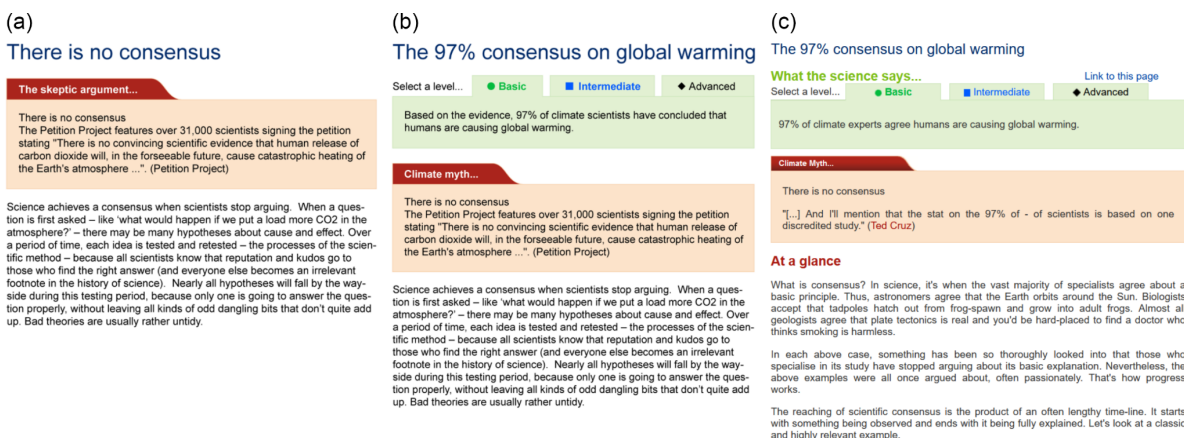
51   Skeptical Science (SkS) is an international website and non-profit science education organization founded by John Cook in 2007.
52   The main purpose of the website is to debunk misconceptions and misinformation about human-caused climate change, featuring
53   more than 250 rebuttals of climate myths. The website is maintained by a team of academics and volunteers from around the
54   globe who actively contribute to published research. One highlight of SkS research output is an often-cited 97% consensus paper
55   (Cook et al., 2013), which was affirmed by a subsequent synthesis of consensus studies (Cook et al., 2016).

56   Other researchers have also drawn upon or analysed Skeptical Science's content. For example, one study analysed user comments
57   on skepticalscience.com, finding that one third of posts indicated a desire to communicate facts or educate (Metcalfe, 2020). The
58   website's encyclopedic list of climate myths has also been influential, with Elsasser & Dunlap (2013) drawing upon the 103 listed
59   rebuttals (at the time) in order to identify the prevalence of specific climate myths in newspaper op-eds. A later analysis of climate
60   denial referenced Skeptical Science's 193 rebuttals (at the time, indicating the steady accumulation of debunkings) as a
61   documentation of "zombie arguments" (Hansson, 2017). The SkS taxonomy of myths also served as the starting point in the
62   inductive development of a comprehensive taxonomy of contrarian claims about climate change (Coan et al., 2021). The website
63   content is currently being used to train models that use generative AI to automatically debunk climate misinformation (Zanartu et
64   al., 2024).

65   The SkS rebuttals are written at multiple levels, offering basic, intermediate, and advanced versions. They tackle common
66   misconceptions about climate change such as "global warming is not happening", "It's not caused by human activity", "Climate
67   impacts are not bad", and "Climate solutions are too hard". The rebuttals receive most of the website's traffic, with some individual
68   rebuttals viewed more than 20,000 times per month. They are listed by popularity, fixed numbers (for ease of reference), or
69   taxonomic categories for ease of access.

1.2 Evolution of SkS Rebuttals

71   The earliest versions of the Skeptical Science rebuttals were initially written for an audience with an intermediate level of scientific
72   knowledge (reflecting the founder John Cook's training in physics). As the site grew and more volunteers contributed, the rebuttals
73   were expanded to include versions for readers with basic, intermediate, and advanced levels of scientific knowledge. The myth
74   rebuttals initially led with and emphasized the myth that was being debunked (Fig. 1a). Subsequently, the rebuttals were adapted
75   using a format to de-emphasise myth according to Schwarz and other studies (Fig. 1b).

76 In late 2022, a thorough rebuttal revision project was initiated, motivated by the years that had passed since some rebuttals had
77 been written and the advances in climate science that had occurred during that time. An initial review of the rebuttal portfolio also
78 identified an accessibility issue, with some rebuttals written at a level that assumed a considerable degree of technical ability on
79 the part of the reader. The remedy was to make the rebuttals accessible to a wider range of readers, with an 'at a glance' primer
80 section added to the start of the basic version of selected rebuttals (Fig. 1c). These primers were comparatively short (500 words
81 or less in length), written in plainer language, and text-only without links, the rationale being to avoid distracting the reader as
82 much as possible. The new 'at a glance' sections led straight into a 'further details' section, being updated versions of the original
83 'basic' rebuttals.

84
85 **Figure 1: (a) First version of rebuttal, (b) Second version of rebuttal with initial fact and basic/intermediate/advanced levels, (c) Current**
86 **version with "At a glance" section.**

87 **2 Methods**

88 This study collected survey data from a selection of visitors to skepticalscience.com. Specifically, visitors who arrived directly at
89 a rebuttal having come from google.com, google.co.uk, or google.com.au were invited to participate in research. Users who arrived
90 at a non-English rebuttal were excluded from the final analysis as the research was conducted in English. Invited visitors were
91 shown a modal pop-up screen asking if they wanted to participate (Fig. 2a). Visitors who indicated they wanted to participate were
92 shown a consent form informing them about the experiment design and how data would be handled (Fig. 2b).

93 If users consented, they were shown a single statement about climate change and asked to indicate their level of agreement on a 6-
94 point Likert scale from "Strongly agree" to "Strongly disagree" (Fig. 2c). "Strongly agree" answers were assigned value 1 while
95 "strongly disagree" answers were assigned value 6. Users were randomly shown either a factual or misinformation statement
96 relevant to the rebuttal (all statements listed in Table A1). Answers to factual statements were reverse scored so that higher values
97 equated to more accurate answers. Once they completed this single survey item, participants proceeded to read the rebuttal. If they
98 scrolled to the end of the rebuttal, indicating that they had read the rebuttal, another modal screen was displayed, inviting them to
99 again indicate their level of agreement with the same factual/misinformation statement. Users who failed to scroll to the end of the
100 rebuttal were not shown the second survey question, and were excluded from the research data. After answering the final question,
101 participants were thanked for their participation and could close the survey (Fig. 2d).

102

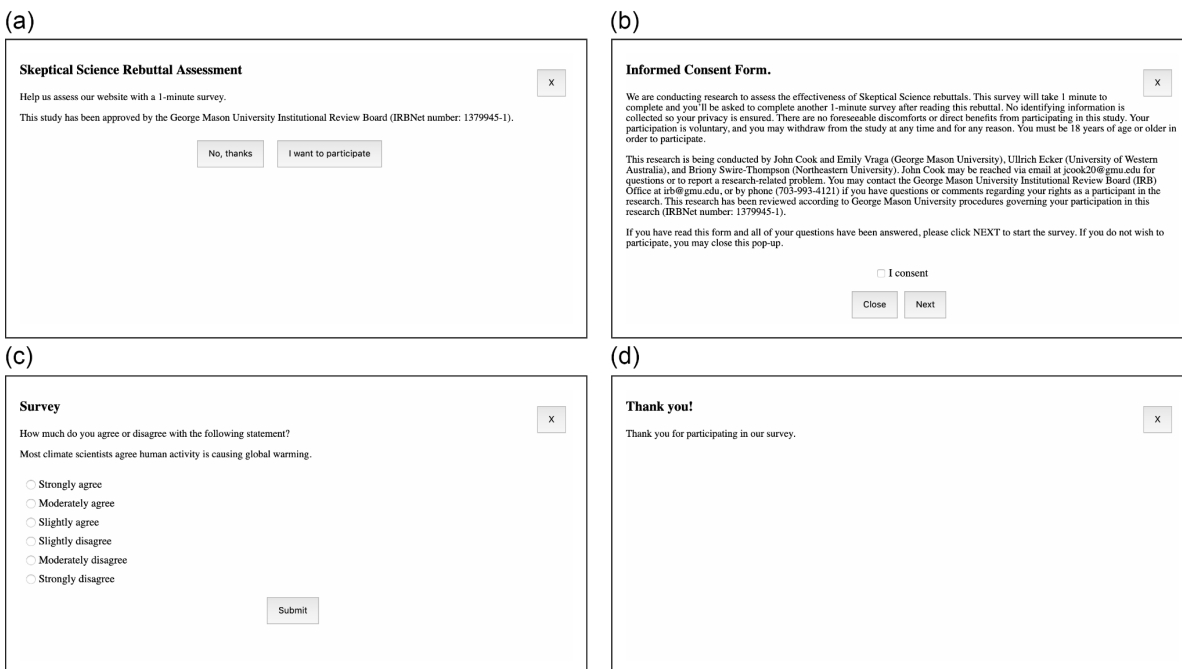
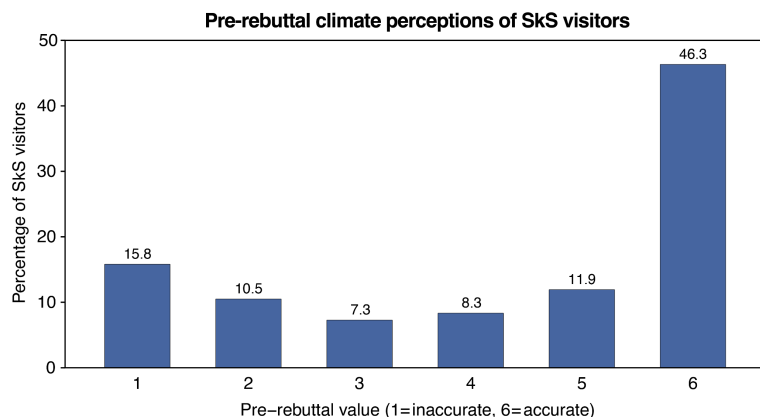
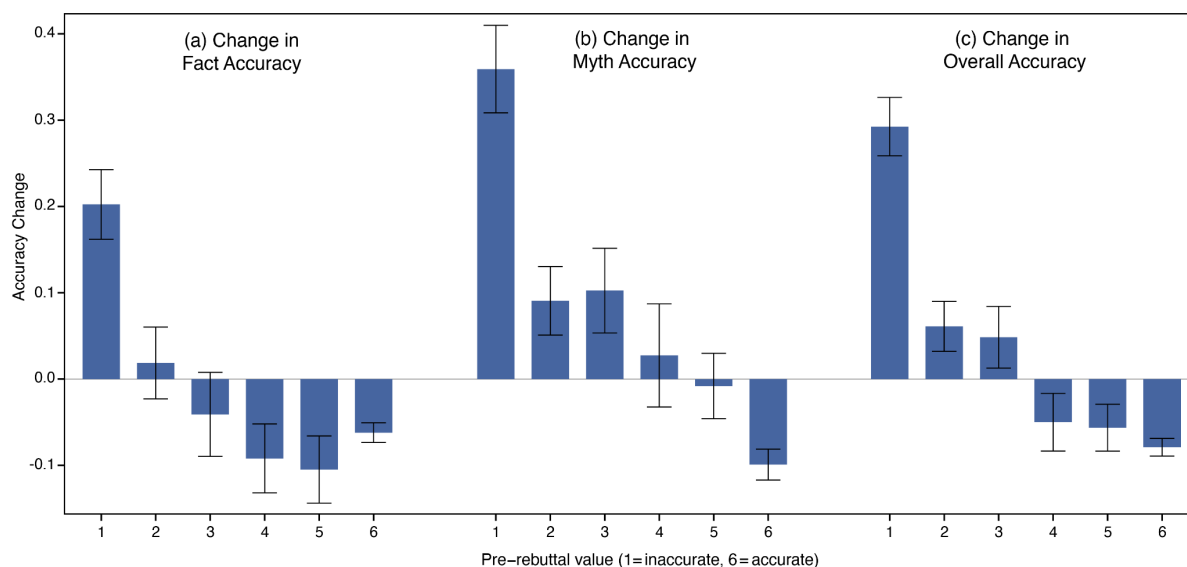



Figure 2: Screenshot of modals used in experiment design. (a) Invitation to participate in research. (b) Informed consent form detailing research design. (c) Survey question. (d) Final thank you modal.

As well as the answer to the survey question, the user's IP address was recorded so that users whose IP address was already listed among existing research participants were not invited upon any subsequent visits. We also recorded Start Time (when the first survey question was loaded) and End Time (when the end survey was loaded). Time Spent was calculated as the difference between End Time and Start Time, noting that this also included the time spent filling out the pre-rebuttal survey. Data collection occurred from November 2021 to July 2025. Over this period, 858,016 visitors were shown the pop-up invitation to participate in research.

3 Results

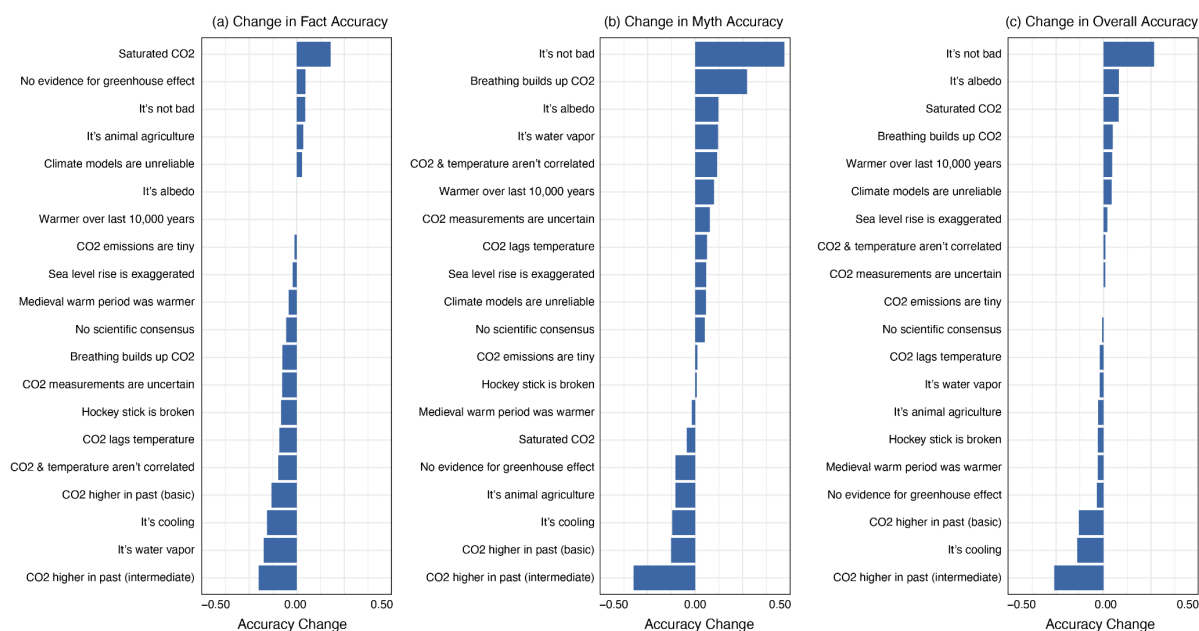
Among the 13,432 people that consented to participate in the research and filled out the pre-rebuttal survey, 6,261 people (46%) went on to fill out the post-rebuttal survey. 3,146 participants were shown a factual statement in the survey quiz while 3,115 were shown a myth statement. The average time spent looking at the rebuttals was 4 minutes, with the median being 1 minute, indicating that readers scrolled through the rebuttal quickly (see Table S1 in the Supplementary Material for a distribution of reading times and speeds). Figure 3 shows the distribution of pre-rebuttal beliefs, revealing that nearly half of the participants (46.3%) showed full agreement with the climate fact or full disagreement with the climate myth. This indicated that the plurality of visitors coming to SkS rebuttals via Google were already strongly convinced about climate change.

119
120 **Figure 3: Distribution of climate perceptions in pre-survey. 1 shows inaccurate answer, 6 shows accurate answer.**

121 To test whether there was an overall shift in climate perceptions, a Wilcoxon Signed-Rank Test revealed a non-significant
122 difference between pre- and post-test scores with a small effect size ($p = 0.49$, $CLES = 0.05$). To examine the change in perceptions
123 in greater detail, we looked at the response to either factual statements or myth statements, shown in Fig. 4a and 4b. Overall, there
124 was a significant decrease in agreement with factual statements ($p = .006$, $CLES = .05$) and a significant decrease in agreement
125 with myth statements ($p = .001$, $CLES = .08$). The overall non-significant result is because the decrease in accuracy in response to
126 the factual statements canceled out the more accurate response to the myth statements.

127
128 **Figure 4: Change in accuracy for different pre-rebuttal values (positive value means increase in accuracy). (a) Change in agreement with**
129 **factual statement, (b) Change in disagreement with misinformation statement, (c) Average change in accuracy for fact and myth**
130 **statements combined.**

131

132 To explore whether the change in perceptions depended on pre-existing perceptions, a hierarchical regression analysis was
133 conducted to examine the moderating effect of pre-rebuttal perception on the change in perception. The results indicated a
134 significant interaction between pre and post ($B = .14$, $t(6258) = 77.7$, $p < .001$). Figure 4c visualizes this dynamic, showing how

135   the improvement in accuracy was greatest for those with the lowest pre-rebuttal perception. Among the people who gave an
136   inaccurate value in the pre-rebuttal survey (1-3), 7.2% switched to an accurate value (4-6) in the post-rebuttal survey.

137   In order to better understand reader response to rebuttals, the change in perception was examined across different individual
138   rebuttals. Figure 5 shows the changes in myth and fact perceptions for rebuttals that recorded at least 50 participants, with positive
139   values representing a shift towards more accurate perceptions. Consistent with Fig. 4, this shows that myth perceptions show on
140   average a more positive improvement in accuracy compared to fact perceptions.

141
142   **Figure 5: Change in accuracy with regard to (a) fact, (b) myth perceptions, and (c) myth and fact combined, for the 20 rebuttals with**
143   **most data.**

144   Some rebuttals consistently perform well for both fact and myth (e.g. "climate impacts aren't bad", see Appendix A6 for links)
145   while other rebuttals perform badly for both fact and myth (e.g., basic and intermediate versions of "co2 was higher in past"). In
146   the case of the water vapor rebuttal, the change in myth perception is one of the best performing rebuttals while the change in fact
147   perception is the worst performing rebuttals.

148   To more closely explore potential explanations for the varied results, the content of the top three and bottom three rebuttals listed
149   in Fig. 5c were qualitatively examined. In particular, the rebuttals were inspected to see whether they possessed a factual
150   explanation that possessed at least the same explanatory relevance as the myth (Ecker et al., 2010) and an explanation of the fallacy
151   the myth used to distort the facts (Cook et al., 2017a). The top three rebuttals span three categories of climate misinformation
152   casting doubt on the reality, cause, and impacts of global warming. The most effective rebuttal debunked the myth "climate impacts
153   are not bad", with the next most effective rebuttals countering the myths "climate change is caused by albedo changes" and
154   "greenhouse effect is saturated."

155   In the rebuttal of "climate impacts are not bad", the replacement fact was that the negative impacts of global warming far
156   outweighed the benefits. This fact is clearly and simply communicated, and reinforced repeatedly as the rebuttal compares negative
157   impacts to benefits across different aspects of the climate (e.g., agriculture, health, polar melting, etc). However, the rebuttal fails
158   to explicitly explain the myth's fallacy, which is cherry picking benefits of climate change while ignoring negative impacts.

159   The rebuttal of "climate change is caused by albedo changes" does explain the relevant fact which is that albedo is a feedback that
160   amplifies climate change rather than a forcing that drives climate change. However, this fact is not highlighted in the "what the
161   science says" box and could have been made more prominent, which may explain why belief in the fact did not increase from this
162   rebuttal. The fallacy in this myth involves cherry picking short periods in order to find spurious correlations between albedo and
163   temperature trends. While the rebuttal does show the long-term trend data which implicitly exposes this fallacy, it fails to explicitly
164   explain the misleading technique.

165   For the rebuttal of the myth "greenhouse effect is saturated," the relevant fact is that more heat is being trapped high up in the
166   atmosphere where the air is thinner (Cook et al., 2015). The rebuttal implicitly alludes to this fact, mentioning the need to consider
167   the greenhouse effect at all levels of the atmosphere, but does not explicitly explain the fact. The rebuttal fails to explain the fallacy
168   of oversimplification, considering the atmosphere as a single layer when it consists of multiple layers (Cook et al., 2018; Flack et
169   al., 2024).

170   The worst and third-worst performing rebuttals were the basic and intermediate rebuttals of "CO2 was higher in the past." This
171   myth argues that because CO2 has been much higher in the Earth's deep past (e.g., over ten times current levels during the
172   Ordovician-Silurian period) without the world burning up, this casts doubt on the warming effect of CO2. The relevant fact is that
173   in the Earth's deep past, the sun was cooler when CO2 was higher with the two forcings roughly balancing each other out (Cook
174   et al., 2015). The myth commits single cause fallacy, a form of oversimplification that fails to consider both factors. Both the basic
175   and intermediate debunkings fail to explain either the fact or the fallacy.

176   The second worst performing rebuttal addressed the myth "it's cooling." The replacement fact communicated in the "What the
177   Science Says" box simply says "it's warming", which is essentially just a negation of the myth without producing any substantive
178   details. The factual explanations delve into complicated details regarding ocean cycles and statistical methods without a clear
179   articulation of how these details relate to the key fact. The rebuttal does explain the fallacy of cherry picking committed by this
180   myth, the only rebuttal examined among both the top three and bottom three rebuttals that explicitly explains the fallacy.

181   **4 Discussion**

182   Our experimental data shed light on the nature of SkS visitors with most visitors (45%) already strongly agreed with climate facts
183   (Fig. 3). This implies that most visitors come to SkS not because they were unsure about a particular climate fact or myth but
184   because they were looking for information to assist them in responding to climate misinformation. In analysing comment threads
185   on SkS, Metcalfe (2020) concluded that commenters seeking out like-minded users was an example of "chanting to the choir."
186   However, a more constructive interpretation of the situation is that the content on the SkS website is "teaching the choir to sing,"
187   providing resources that empower people to respond to climate misinformation (Swim & Fraser, & Geiger, 2014). Such a service
188   is particularly important given that a major reason why people self-censor and avoid talking about climate change with friends and
189   family is due to fear of push-back from climate contrarians (Geiger & Swim 2016). This avoidance of climate change as a
190   discussion topic, known as climate silence, is self-reinforcing leading to a "spiral of silence" (Maibach et al., 2016). On the other
191   hand, discussing climate change raises awareness of the issue, which leads to more discussion in a positive feedback loop (Goldberg
192   et al., 2019).

193   Also conflicting with the "chanting to the choir" interpretation is the finding that the greatest improvement in accurate perceptions
194   was observed among those with the strongest disagreement with climate facts or strongest agreement with climate myths. This was
195   an encouraging result, showing the website is effective in changing the minds of those most dismissive about climate change.
196   However, a concerning result was that overall, there was a decrease in agreement with climate facts. A key goal of misinformation
197   interventions is to increase reader discernment, the difference between belief in facts and belief in myths (Pennycook & Rand,
198   2021). While there was overall an increase in discernment, with the decrease in agreement with myths greater than the decrease in

199   agreement with facts, the result that belief in climate facts decreased for at least some rebuttals is unwelcome and counter to the
200   goal of SkS.

201   Inspection of the top three and bottom three rebuttals offers insights into how rebuttals could be made more effective. The better
202   performing rebuttals identified relevant replacement facts that offered equal or greater explanatory relevance than the myths,
203   explained clearly and simply, while the worst performing rebuttals failed to clearly explain replacement facts. In addition, explicit
204   explanations of the fallacies used by climate myths should also be integrated into the rebuttals, offering a seamless fact-myth-
205   fallacy debunking structure (Lewandowsky et al., 2020). Currently, the website is being redesigned with plans to integrate fallacy
206   explanations into the updated content infrastructure and rebuttal design, in line with research showing the effectiveness of fallacy
207   explanations (Cook et al., 2017a). Intuitively, it is expected that this might have a greater impact on lowering agreement with myths
208   than on increasing agreement with facts. Future research should assess the updated effectiveness of rebuttals that are more
209   intentional in including replacement facts and fallacy explanations. Another way to gain deeper insight into the impact of rebuttals
210   on readers would be to collect open-ended feedback from participants in the post-rebuttal survey. Qualitative data with the user
211   reflecting on the readability or comprehensibility of the rebuttal might offer guidance on potential problems with specific rebuttals.

212   Lastly, recent research indicates that climate misinformation is transitioning from science denial to arguments against climate
213   solutions (Coan et al., 2021), with increasing attention being paid to the so-called "discourses of delay" – framings and narratives
214   designed to delay climate action (Lamb et al., 2020). While SkS has largely focused on climate science myths over its history, it
215   has recently begun incorporating more rebuttals of solutions myths. A collaboration with The Sabin Center for Climate Change
216   Law at Columbia Law School involved adapting their rebuttals of 33 renewable myths into SkS rebuttals (Eisenson et al., 2023).
217   Experimentally testing the impact of these rebuttals would be a useful area of future research to measure their effectiveness in
218   countering misinformation targeting climate solutions.

219   In summary, collecting quantitative survey data on a live website is technically and scientifically challenging but offers the
220   opportunity to gain deep insights into pre-existing and updated perceptions of visitors after reading website content. In this study,
221   we obtained insights into climate perceptions of visitors as they arrived at the website, implying that visitors were looking for
222   scientific information enabling them to respond to misinformation. We also learned that our rebuttals decreased belief in climate
223   myths and improved discernment – the difference between belief in facts and myths. However, we also observed a decrease in
224   climate facts, an unwelcome result necessitating investigation into possible causes. In turn, the subsequent analysis offered
225   guidance on ways that the rebuttals could be updated to be more effective, bringing them in line with the recommendations of
226   psychological research.

227

228 **Appendices**

229 **A1 Table of Fact and Myth Statements**

230 **Table A1: Factual and misinformation statements used in pre-rebuttal and post-rebuttal surveys.**

Myth	Factual Statement	Misinformation Statement
"It's cooling", "DMI show cooling Arctic"	I am certain that global warming is really happening.	The climate is not really warming.
"Ice isn't melting", "Arctic sea ice loss is matched by Antarctic sea ice gain"	Ice is melting at an accelerating rate.	Ice is not in danger of melting.
"We're heading into cooling", "We're heading into an ice age", "A grand solar minimum could trigger another ice age"	Earth's climate is headed into future warming.	Earth's climate is headed into another ice age.
"It's freaking cold!", "Record high snow cover was set in winter 2008/2009", "Record snowfall disproves global warming", "2009-2010 winter saw record cold spells"	Global warming makes hot days more likely and cold days less likely.	Recent cold weather is evidence that the climate is not warming
"No warming in 16 years", "Phil Jones says no global warming since 1995", "It hasn't warmed since 1998", "BEST hides the decline in global temperature", "IPCC admits global warming has paused", "They changed the name from 'global warming' to 'climate change'", "Oceans are cooling", "Springs aren't advancing", "Global warming stopped in ~~1998~~,~~1995~~, ~~2002~~, ~~2007~~, ~~2010~~, ????", "Trenberth can't account for the lack of warming", "Satellites show no warming in the troposphere", "It's not happening"	Over the past few decades, the world's average temperature has been increasing.	Over the past few decades, the world's average temperature has not been increasing.
"Sea level rise is exaggerated", "Sea level rise is decelerating", "Sea level rise predictions are exaggerated", "Scientists retracted claim that sea levels are rising", "Sea level is not rising", "Sea level fell in 2010", "Tuvalu sea level isn't rising"	Sea level rise has been steadily accelerating over the past century.	The seriousness of sea level rise is exaggerated.
"Climate change isn't increasing extreme weather damage costs", "Extreme weather isn't caused by global warming", "Heatwaves have happened before", "Hurricanes aren't linked to global warming", "The connection between Hurricane Sandy and global warming"	Climate change is increasing the risk of extreme weather.	Extreme weather is not increasing, there is just more reporting of it in the media these days.
"There's no correlation between CO2 and temperature", "It's El Nino", "Animal agriculture and eating meat are the biggest causes of global warming", "It's methane", "It's microsite influences", "It's satellite microwave transmissions", "Nuclear testing is causing global warming", "It's the ocean", "It's ozone", "It's Pacific Decadal Oscillation", "It's planetary movements", "It's a climate regime shift", "It's soot", "It's a climate shift step function caused by natural cycles", "Underground temperatures control climate", "It's internal variability", "A drop in volcanic activity caused warming", "It's waste heat"	Human activities are changing the climate	Climate change is just a result of natural variation in the climate.
"Mt. Kilimanjaro's ice loss is due to land use", "It's land use"	Most of the warming over the last 50 years is due to the increase in greenhouse gas concentrations	Climate change is due to non- greenhouse gas factors like land use.
"Greenhouse effect has been falsified", "Increasing CO2 has little to no effect", "There's no tropospheric hot spot", "We didn't have global warming during the Industrial Revolution", "CO2 was higher in the late Ordovician", "CO2 was higher in the past", "Postma disproved the greenhouse effect", "Removing all CO2 would make little difference", "CO2 has a short residence time", "CO2 effect is saturated", "2nd law of thermodynamics contradicts greenhouse theory", "CO2 is just a trace gas", "Water vapor is the most powerful greenhouse gas", "Venus doesn't have a runaway greenhouse effect"	Greenhouse gases in the atmosphere affect the average global temperature of the Earth.	Increasing greenhouse gases in the atmosphere has little to no effect on climate.
"Breathing contributes to CO2 buildup", "CO2 emissions do not correlate with CO2 concentration", "CO2 increase is natural, not human-caused", "Murry Salby finds CO2 rise is natural"	CO2 emissions from fossil fuel burning have caused atmospheric CO2 levels to increase by over 40%.	CO2 emissions from fossil fuel burning is not the cause of the increase in CO2 levels in the atmosphere.
"It's only a few degrees", "It's not bad", "An exponential increase in CO2 will result in a linear increase	The effects of climate	I do not believe climate

in temperature", "It's not urgent"	change are likely to be catastrophic.	change is a real problem.
"Clouds provide negative feedback", "Humidity is falling", "Infrared Iris will reduce global warming", "Lindzen and Choi find low climate sensitivity", "No long tail means climate sensitivity is low", "Roy Spencer finds negative feedback", "Positive feedback means runaway warming", "Schmittner finds low climate sensitivity", "Climate sensitivity is low", "Water vapor in the stratosphere stopped global warming", "Tropical thermostat limits sea surface temperature to 30C"	The climate is highly sensitive to changes in heat.	Negative feedbacks mean climate sensitivity is low.
"Animals and plants can adapt"	Global warming will harm animal and plant species.	Global warming is no danger to animal and plant species.
"CO2 is not a pollutant"	Rising carbon dioxide in the atmosphere presents a danger to people and the environment.	Carbon dioxide is natural; therefore, it is safe.
"Adapting to global warming is cheaper than preventing it", "It's too hard"	Humans can reduce global warming, and we are going to do so successfully.	Humans can't reduce global warming, even if it is happening.
"CO2 limits will harm the economy", "Renewable energy investment kills jobs", "CO2 limits will hurt the poor"	The economic benefits of climate action outweigh the costs.	Climate action is bad for the economy.
"CO2 limits won't cool the planet"	With strong climate action, we can make significant impact on slowing climate change.	Climate action will have little impact on slowing climate change.
"Renewables can't provide baseload power", "Renewable energy is too expensive"	We need many different strategies to reduce CO2 emissions and avoid climate change.	Renewable technology like solar power cannot help us reduce global warming.
"Climate 'Skeptics' are like Galileo", "The science isn't settled"	There is a strong body of evidence for climate change.	The evidence for climate change is unreliable.
"CO2 measurements are suspect", "Tree-rings diverge from temperature after 1960", "Dropped stations introduce warming bias", "Satellite error inflated Great Lakes temperatures", "Hockey stick is broken", "Ljungqvist broke the hockey stick", "Mauna Loa is a volcano", "Satellite record is more reliable than thermometers", "Plant stomata show higher and more variable CO2 levels", "Temp record is unreliable", "UAH atmospheric temperatures prove climate models and/or surface temperature data sets are wrong", "It's Urban Heat Island effect"	Climate measurements are accurate.	Climate measurements are unreliable.
"Climategate CRU emails suggest conspiracy", "Scientists tried to 'hide the decline' in global temperature", "Freedom of Information (FOI) requests were ignored", "Climate scientists are in it for the money", "Climate science peer review is pal review", "Peer review process was corrupted", "CRU tampered with temperature data"	Climate scientists are sincere in their research into climate.	Climate change is a hoax to generate money for scientists.
"Antarctica is gaining ice", "Southern sea ice is increasing", "Antarctica is too cold to lose ice"	Antarctica is losing land ice at an accelerating rate, contributing to sea level rise.	Antarctica is gaining ice, casting doubt on global warming.
"Greenland is gaining ice", "Greenland ice sheet won't collapse", "Greenland has only lost a tiny fraction of its ice mass", "Ice Sheet losses are overestimated"	Greenland is losing ice at an accelerating rate.	Greenland is not in danger of melting.
"Melting ice isn't warming the Arctic", "Arctic sea ice has recovered", "Arctic icemelt is a natural cycle", "Arctic Storm Caused the 2012 Record Sea Ice Minimum"	Arctic sea ice is in long-term retreat, losing half its coverage in only 40 years.	Arctic sea ice is not in danger of melting.

"Glaciers are growing", "Himalayan glaciers are not shrinking"	Glaciers are in long-term retreat.	Glaciers are not in danger of melting.
"The sun is getting hotter", "Solar Cycle Length proves its the sun", "Solar cycles cause global warming", "It's the sun", "Water levels correlate with sunspots", "Jupiter is warming", "Mars is warming", "Neptune is warming", "Other planets are warming", "Pluto is warming"	Over the last few decades of global warming, the sun has been cooling and cannot be causing recent warming.	Other planets showing warming means the sun is causing global warming.
"It's a 1500 year cycle", "CO2 only causes 35% of global warming", "It's aerosols", "It's not us", "Akasofu Proved Global Warming is Just a Recovery from the Little Ice Age", "It's albedo", "It's global brightening", "CERN CLOUD experiment proved cosmic rays are causing global warming", "It's CFCs", "It's cosmic rays", "It's a natural cycle", "CO2 is not the only driver of climate", "There's no empirical evidence", "Greenland was green", "We're coming out of the Little Ice Age", "Loehle and Scafetta find a 60 year cycle causing global warming", "It cooled mid-century", "Medieval Warm Period was warmer", "Northwest passage has been navigated in the past", "Climate's changed before", "It warmed before 1940 when CO2 was low", "Humans are too insignificant to affect global climate", "Soares finds lack of correlation between CO2 and temperature", "Humans survived past climate changes", "It warmed just as fast in 1860-1880 and 1910-1940"	Most of the warming over the last 50 years is due to the increase in greenhouse gas concentrations.	The climate is always changing and what we are currently observing is just natural fluctuation.
"Most of the last 10,000 years were warmer", "1934 - hottest year on record", "Arctic was warmer in 1940"	Modern climate change is abrupt and driven by human activity, setting it apart from past climate change.	It's been hotter in the past, therefore humans are not the cause of current global warming.
"CO2 lags temperature"	More CO2 causes more warming and warming causes more CO2, combining to create a reinforcing feedback.	CO2 lagged temperature in the past, disproving the warming effect of CO2.
"Human CO2 is a tiny % of CO2 emissions", "CO2 is coming from the ocean", "Volcanoes emit more CO2 than humans", "Warming causes CO2 rise"	CO2 emissions from fossil fuel burning have upset the carbon cycle which was in natural balance.	Nature produces more carbon dioxide than humans.
"CO2 is not increasing"	CO2 emissions from fossil fuel burning have caused atmospheric CO2 levels to increase by over 40%.	CO2 levels in the atmosphere are not increasing appreciably.
"Polar bear numbers are increasing"	Global warming will harm polar bears.	Global warming is no danger to polar bears.
"Ocean acidification isn't serious", "Coral atolls grow as sea levels rise", "Corals are resilient to bleaching", "Great Barrier Reef is in good shape"	Global warming will harm ocean ecosystems.	Global warming is no danger to ocean ecosystems
"CO2 is plant food"	Plants need the right amount of water to flourish - climate change upsets that balance.	CO2 is plant food so CO2 emissions are good for plants.
"500 scientists refute the consensus", "There is no consensus", "Deniers are part of the 97%", "The IPCC consensus is phoney", "Over 31,000 scientists signed the OISM Petition Project", "Naomi Oreskes' study on consensus was flawed", "97% consensus on human-caused global warming has been disproven", "Royal Society embraces skepticism", "Less than half of published scientists endorse global warming"	Most climate scientists agree human activity is causing global warming.	There is a lot of disagreement among climate scientists about whether human activity is causing global warming.
"Earth hasn't warmed as much as expected", "Models are unreliable", "Climate is chaotic and cannot be predicted", "Scientists can't even predict weather"	Climate models have been successful at predicting global warming over long time periods.	Scientists' computer models are too unreliable to predict the climate of the future.
"Ice age predicted in the 70s"	Most climate research	Scientists were wrong

	in the 1970s predicted future global warming.	about ice age predictions in the 1970s so can't be trusted now.
"Al Gore got it wrong"	Al Gore is trustworthy in how he treats climate research.	Al Gore is not trustworthy in how he treats climate research.
"Hansen's 1988 prediction was wrong", "Hansen predicted the West Side Highway would be underwater"	Climate scientists are trustworthy in how they do climate research.	Climate scientists are not trustworthy in how they do climate research.
"IPCC graph showing accelerating trends is misleading", "IPCC were wrong about Amazon rainforests", "IPCC human-caused global warming attribution confidence is unfounded", "IPCC were wrong about Himalayan glaciers", "IPCC disappeared the Medieval Warm Period", "IPCC edited out natural causes of climate change", "Skeptics were kept out of the IPCC?", "IPCC overestimate temperature rise", "IPCC global warming projections were wrong", "Ben Santer rewrote the 1995 IPCC report", "IPCC is alarmist"	The Intergovernmental Panel on Climate Change (IPCC) is trustworthy in how they treat climate research.	The Intergovernmental Panel on Climate Change (IPCC) is not trustworthy in how they treat climate research.

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232

233 **A2 Handbooks**

234 *The Debunking Handbook*

235 Skeptical Science also provides downloadable materials such as handbooks devoted to various aspects of misinformation research.

236 The **Debunking Handbook** is a consensus document written by 19 co-authors invited by the three lead authors Stephan

237 Lewandowsky, John Cook and Ullrich Ecker based on their scientific status in the field. The Handbook explains what mis- and

238 disinformation is, why it can cause substantial harm for individuals and societies, why it is often sticky and therefore hard to

239 dislodge, why pre-bunking can be more effective than debunking and how to go about the latter best. As of July 2025, this handbook

240 has been translated into 20 languages.

241 Cite: Lewandowsky, S., Cook, J., Ecker, U. K. H., Albarracín, D., Amazeen, M. A., Kendeou, P., Lombardi, D., Newman, E. J.,
242 Pennycook, G., Porter, E. Rand, D. G., Rapp, D. N., Reifler, J., Roozenbeek, J., Schmid, P., Seifert, C. M., Sinatra, G. M., Swire-
243 Thompson, B., van der Linden, S., Vraga, E. K., Wood, T. J., Zaragoza, M. S. (2020). The Debunking Handbook 2020. Available
244 at https://sks.to/db2020. DOI:10.17910/b7.1182

245 **The Conspiracy Theory Handbook**

246 Conspiracy theories attempt to explain events as the secretive plots of powerful people. While conspiracy theories are not typically

247 supported by evidence, this doesn't stop them from blossoming. Conspiracy theories damage society in a number of ways. To help

248 minimize these harmful effects, **The Conspiracy Theory Handbook** written by Stephan Lewandowsky and John Cook explains

249 why conspiracy theories are so popular, how to identify the traits of conspiratorial thinking, and what effective response strategies

250 are. As of July 2025, this handbook has been translated into 20 languages. The Handbook distills the most important research

251 findings and expert advice on dealing with conspiracy theories. It also introduces the abbreviation CONSPIR which serves as a

252 mnemonic to more easily remember the seven traits of conspiratorial thinking: They are contradictory, contain overriding

253 suspicion, have nefarious intent, something must be wrong, peddlers of conspiracy theories see themselves as persecuted victmis,

254 they are immune to evidence and are re-interpreting randomness.

255 Cite: Lewandowsky, S., & Cook, J. (2020). The Conspiracy Theory Handbook. Available at http://sks.to/conspiracy

256 **A3 Massive Open Online Course: Denial101x**

257 In 2015, the Skeptical Science team in collaboration with the University of Queensland produced a Massive Open Online Course

258 (MOOC) titled Denial101x: Making Sense of Climate Science Denial (Cook et al., 2017b; Winkler & Cook, 2021). Included the

259 fact-myth-fallacy resource (published at sks.to/fmf).

260 **A4 Translations**

261 In 2009, translation capabilities for rebuttals were added to the website and since then, 1086 translations have been published in

262 25 languages by volunteer translators. For some languages there are less than 5 translations while others have up to 213. Table A2

263 shows the top 15 languages by number of published translations.

264

265   **Table A2. Number of Translations into each Language.**

Language	Translations
German	213
Italian	136
Russian	108
Portuguese	99
Indonesian	60
Slovenian	60
Hebrew	58
Finnish	52
Polish	46
Czech	37
Spanish	35
Hungarian	27
Japanese	25
Dutch	23
Icelandic	17

266

267   **A5 Conference presentations**

268   Winkler, B., Cook, J. (2020). The story of Skeptical Science: How citizen science helped to turn a website into a go-to resource
269   for climate science. EGU 2020.

270   Winkler, B. and Cook, J.: Using an interdisciplinary MOOC to teach climate science and science communication to a global
271   classroom, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-8576, https://doi.org/10.5194/egusphere-
272   egu21-8576, 2021. PDF

273   **A6 Links to Skeptical Science Content and Resources**

274   **A6.1 Skeptical Science content**

275   Website - https://skepticalsicence.com

276   Evolution from 2007 to 2017 - https://skepticalscience.com/SkepticalScience-10-Birthday.html

277   Activities 2017 - https://skepticalscience.com/2017-SkS-Review.html

278   Activities 2018 - https://skepticalscience.com/2018-SkS-Review.html

279 Activities 2019 - https://skepticalscience.com/2019-SkS-Review.html

280 Activities 2020 - https://skepticalscience.com/2020-SkS-Review.html

281 Activities 2021 - https://skepticalscience.com/2021-SkS-Review.html

282 Activities 2022 - https://skepticalscience.com/2022-SkS-Review.html

283 Activities 2023 - https://skepticalscience.com/2023-SkS-Review.html

284 Activities 2024 - https://skepticalscience.com/2024-SkS-Review.html

285 List of arguments - https://skepticalscience.com/argument.php

286 Taxonomy of arguments - https://skepticalscience.com/argument.php?f=taxonomy

287 With fixed numbers - https://skepticalscience.com/fixednum.php

288 Announcing the 3 rebuttal levels - https://skepticalscience.com/Plain-English-climate-science-now-live-at-Skeptical-
289 Science.html

290 Rebuttal updates project - https://skepticalscience.com/rebuttal-update-project.html

291 Collaboration with the Sabin Center for Climate Change Law - https://skepticalscience.com/rebutting-33-false-claims-about-
292 solar-wind-ev-introduction.html

293 FLICC-techniques of science denial - https://skepticalscience.com/history-FLICC-5-techniques-science-denial.html

294 **A6.2 Myths and Rebuttals Referenced**

295 It's not happening - https://skepticalscience.com/evidence-for-global-warming.htm

296 It's not us - https://skepticalscience.com/its-not-us.htm

297 It's not bad - https://skepticalscience.com/global-warming-positives-negatives.htm

298 It's too hard - https://skepticalscience.com/global-warming-too-hard.htm

299 CO2 was higher in the past - basic - https://skepticalscience.com/co2-higher-in-past-basic.htm

300 CO2 was higher in the past - intermediate - https://skepticalscience.com/co2-higher-in-past-intermediate.htm

301 Water vapor is the most powerful greenhouse gas -
302 https://skepticalscience.com/water-vapor-greenhouse-gas.htm

303 It's albedo - https://skepticalscience.com/earth-albedo-effect.htm

304 CO2-effect is saturated - https://skepticalscience.com/saturated-co2-effect.htm

305 It's cooling - https://skepticalscience.com/global-cooling.htm

306 There is no consensus - https://skepticalscience.com/global-warming-scientific-consensus.htm

Data Availability

Anonymised data has been uploaded to https://osf.io/jnce4/

Author Contributions

JC and BW contributed data analysis and writing of results. CM, TL, DB contributed descriptions of experimental implementation. DN contributed writing of manuscript.

Competing interests

The authors declare that they have no conflict of interest.

Ethical statement

This study was conducted with ethics approval obtained from the George Mason University Institutional Review Board (IRBNet number: 1379945-1).

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324 **References**

325 Bentley, A. P., Petcovic, H. L., Cassidy, D. P., & Eklund, P. R. (2016, December). The Relationship between Anthropogenic
326   Climate Change Acceptance and Agreement with Authentic Dissenter Messages. In AGU Fall Meeting Abstracts (Vol.
327   2016, pp. ED33D-0909).

328 Coan, T. G., Boussalis, C., Cook, J., & Nanko, M. O. (2021). Computer-assisted classification of contrarian claims about climate
329   change. *Scientific Reports*, *11*(1), 22320.

330 Cook, J., Ellerton, P., & Kinkead, D. (2018). Deconstructing climate misinformation to identify reasoning errors. *Environmental*
331   *Research Letters*, *11*(2).

332 Cook, J., Lewandowsky, S., & Ecker, U. (2017a). Neutralizing misinformation through inoculation: Exposing misleading
333   argumentation techniques reduces their influence. *PLOS ONE*, *12*(5): e0175799.

334 Cook, J., Nuccitelli, D., Green, S.A., Richardson, M., Winkler, B., Painting, R., Way, R., Jacobs, P., & Skuce, A. (2013).
335   Quantifying the consensus on anthropogenic global warming in the scientific literature. *Environmental Research Letters*,
336   *8*(2), 024024+.

337 Cook, J, Oreskes, N., Doran, P. T., Anderegg, W. R. L., Verheggen, B., Maibach, E. W., Carlton, J.S., Lewandowsky, S., Green,
338   S. A., Skuce, A. G., Nuccitelli, D., Jacobs, P., Richardson, M., Winkler, B., Painting, R., Rice, K. (2016). Consensus on
339   consensus: a synthesis of consensus estimates on human-caused global warming. *Environmental Research Letters*, *11*(4),
340   048002.

341 Cook, J., Schuennemann, K., Nuccitelli, D., Jacobs, P., Cowtan, K., Green, S., Way, R., Richardson, M., Cawley, G., Mandia, S.,
342   Skuce, A. & Bedford, D. (2015). Denial101x: Making sense of climate science denial. *edX*. Retrieved from
343   http://edx.org/understanding-climate-denial.

344 Cook, J., Winkler, B., Finn, C., & Dodgen, T. (2017b, January). Challenges and learning opportunities in a controversial MOOC
345   forum on climate science denial. In *10th International Conference of Education, Research and Innovation (Iceri2017)* (pp.
346   3460-3468). IATED Academy.

347 Ecker, U. K., Lewandowsky, S., & Tang, D. T. (2010). Explicit warnings reduce but do not eliminate the continued influence of
348   misinformation. *Memory & Cognition*, *38*(8), 1087-1100.

349 Eisenson, M., Elkin, J., Fitch, A., Ard, M., Sittinger, K., Lavine, S. (2023). Rebutting 33 false claims about solar, wind, and electric
350   vehicles. *Sabin Center for Climate Change Law*. https://climate.law.columbia.edu/news/sabin-center-releases-new-report-
351   rebutting-33-false-claims-about-solar-wind-and-electric .

352 Elsasser, S. W., & Dunlap, R. E. (2013). Leading voices in the denier choir: Conservative columnists' dismissal of global warming
353   and denigration of climate science. *American Behavioral Scientist*, *57*(6), 754-776.

354 Flack, R., Cook, J., Ellerton, P., Kinkead, D., Coan, T., Boussalis, C., Nanko, M. O., Gallant, A., Dargaville, R. (2024). Identifying
355   Flawed Reasoning in Contrarian Claims about Climate Change. *Online at https://osf.io/preprints/psyarxiv/tk76c*

356 Geiger, N., & Swim, J. K. (2016). Climate of silence: Pluralistic ignorance as a barrier to climate change discussion. *Journal of*
357   *Environmental Psychology*, *47*, 79-90.

358 Goldberg, M. H., van der Linden, S., Maibach, E., & Leiserowitz, A. (2019). Discussing global warming leads to greater acceptance
359   of climate science. Proceedings of the National Academy of Sciences, 116(30), 14804-14805.

360   Hansson, S. O. (2017). Science denial as a form of pseudoscience. *Studies in History and Philosophy of Science Part A*, *63*, 39-47.

361   Jolley, D., & Douglas, K. M. (2014). The social consequences of conspiracism: Exposure to conspiracy theories decreases
362   intentions to engage in politics and to reduce one's carbon footprint. *British Journal of Psychology*, *105*(1), 35-56.

363   Lamb, W. F., Mattioli, G., Levi, S., Roberts, J. T., Capstick, S., Creutzig, F., Minx, J. C., Müller-Hansen,. F., Culhane, T., &
364   Steinberger, J. K. (2020). Discourses of climate delay. *Global Sustainability*, 3, e17.

365   Leiserowitz, A., Smith, N., & Marlon, J. R. (2011). American teens' knowledge of climate change. Yale University. New Haven,
366   CT: Yale Project on Climate Change Communication, 5.

367   Lewandowsky, S., Cook, J., Ecker, U. K. H., Albarracín, D., Amazeen, M. A., Kendeou, P., Lombardi, D., Newman, E. J.,
368   Pennycook, G., Porter, E. Rand, D. G., Rapp, D. N., Reifler, J., Roozenbeek, J., Schmid, P., Seifert, C. M., Sinatra, G. M.,
369   Swire-Thompson, B., van der Linden, S., Vraga, E. K., Wood, T. J., Zaragoza, M. S. (2020). *The Debunking Handbook*
370   *2020.* https://doi.org/10.17910/b7.1182

371   Lewandowsky, S., Oreskes, N., Risbey, J. S., Newell, B. R., & Smithson, M. (2015). Seepage: Climate change denial and its effect
372   on the scientific community. *Global Environmental Change*, *33*, 1-13.

373   Ling, M., Head, A., & Clarke, E. J. R. (2019). Validation of a Novel Climate Change Denial Measure Using Item Response Theory.
374   https://doi.org/10.31234/osf.io/57nbk

375   Maibach, E, Leiserowitz, A, Rosenthal, S, Roser-Renouf, C & Cutler, M 2016, *Is There a Climate "Spiral of Silence" in America:*
376   *March, 2016*, Yale Program on Climate Change Communication, New Haven, CT.

377   McCright, A. M., Charters, M., Dentzman, K., & Dietz, T. (2016). Examining the effectiveness of climate change frames in the
378   face of a climate change denial counter-frame. *Topics in cognitive science*, *8*(1), 76-97.

379   Metcalfe, J. (2020). Chanting to the choir: the dialogical failure of antithetical climate change blogs. *Journal of Science*
380   *Communication*, *19*(2), A04.

381   Pennycook, G., Cannon, T. D., & Rand, D. G. (2018). Prior exposure increases perceived accuracy of fake news. *Journal of*
382   *Experimental Psychology: General*, *147*(12), 1865.

383   Ranney, M.A. & Clark, D. (2016). Climate Change Conceptual Change: Scientific Information Can Transform Attitudes. *Topics*
384   *in Cognitive Science*, *8*(1), 49-75.

385   Seifert, C. M. (2002). The continued influence of misinformation in memory: What makes a correction effective? In *Psychology*
386   *of learning and motivation* (Vol. 41, pp. 265-292). Academic Press.

387   Swim, J. K., Fraser, J., & Geiger, N. (2014). Teaching the choir to sing: Use of social science information to promote public
388   discourse on climate change. *Journal of Land Use & Environmental Law*, 91-117.

389   van der Linden, S. (2015). The conspiracy-effect: Exposure to conspiracy theories (about global warming) decreases pro-social
390   behavior and science acceptance. *Personality and Individual Differences*, *87*, 171-173.

391   van der Linden, S., Leiserowitz, A., Rosenthal, S., & Maibach, E. (2017). Inoculating the Public against Misinformation about
392   Climate Change. *Global Challenges*, *1*(2), 1600008.

393   Vraga, E. K., Kim, S. C., Cook, J., & Bode, L. (2020). Testing the effectiveness of correction placement and type on Instagram.
394   *The International Journal of Press/Politics*, *25*(4), 632-652.

395   Winkler, B. and Cook, J. (2021). Using an interdisciplinary MOOC to teach climate science and science communication to a global
396   classroom, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-8576, https://doi.org/10.5194/egusphere-egu21-
397   8576. PDF

398   Zanartu, F., Cook, J., Frermann, L., Otmakhova, Y. (2024). Generative Debunking of Climate Misinformation. *ClimateNLP 2024*
399   *Workshop*. https://arxiv.org/abs/2407.05599