

LETTER • OPEN ACCESS

Deconstructing climate misinformation to identify reasoning errors

To cite this article: John Cook *et al* 2018 *Environ. Res. Lett.* **13** 024018

View the [article online](#) for updates and enhancements.

Environmental Research Letters



LETTER

Deconstructing climate misinformation to identify reasoning errors

OPEN ACCESS

RECEIVED

21 September 2017

REVISED

7 December 2017

ACCEPTED FOR PUBLICATION

2 January 2018

PUBLISHED

6 February 2018

Original content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](#).

Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.



John Cook^{1,3} , Peter Ellerton² and David Kinkead²

¹ Center for Climate Change Communication, George Mason University, Fairfax, VA, United States of America

² University of Queensland Critical Thinking Project, Brisbane, QLD, Australia

³ Author to whom any correspondence should be addressed.

E-mail: jcook20@gmu.edu

Keywords: climate change, critical thinking, misinformation, inoculation

Supplementary material for this article is available [online](#)

Abstract

Misinformation can have significant societal consequences. For example, misinformation about climate change has confused the public and stalled support for mitigation policies. When people lack the expertise and skill to evaluate the science behind a claim, they typically rely on heuristics such as substituting judgment about something complex (i.e. climate science) with judgment about something simple (i.e. the character of people who speak about climate science) and are therefore vulnerable to misleading information. Inoculation theory offers one approach to effectively neutralize the influence of misinformation. Typically, inoculations convey resistance by providing people with information that counters misinformation. In contrast, we propose inoculating against misinformation by explaining the fallacious reasoning within misleading denialist claims. We offer a strategy based on critical thinking methods to analyse and detect poor reasoning within denialist claims. This strategy includes detailing argument structure, determining the truth of the premises, and checking for validity, hidden premises, or ambiguous language. Focusing on argument structure also facilitates the identification of reasoning fallacies by locating them in the reasoning process. Because this reason-based form of inoculation is based on general critical thinking methods, it offers the distinct advantage of being accessible to those who lack expertise in climate science. We applied this approach to 42 common denialist claims and find that they all demonstrate fallacious reasoning and fail to refute the scientific consensus regarding anthropogenic global warming. This comprehensive deconstruction and refutation of the most common denialist claims about climate change is designed to act as a resource for communicators and educators who teach climate science and/or critical thinking.

1. Introduction

Misinformation, defined as information initially presented as true that is later found to be false (Lewandowsky *et al* 2012), is a societal issue of growing concern. The World Economic Forum listed online misinformation as one of the top ten global trends threatening the world (WEF 2014). Oxford Dictionary named ‘post-truth’ the 2016 word of the year (Flood 2016) while Collins Dictionary named ‘fake news’ the 2017 word of the year (Flood 2017) in recognition of the prevalence and impact of misinformation.

The issue of climate change has been particularly impacted by misinformation. There is an overwhelming scientific consensus that humans are causing global warming (Cook *et al* 2016), with a number of studies converging on 97% agreement among publishing climate scientists or relevant climate papers (Doran and Zimmerman 2009, Anderegg *et al* 2010, Cook *et al* 2013, Carlton *et al* 2015). However, there is little awareness of the scientific consensus among the general public with only 12% of Americans aware that the consensus is above 90% (Leiserowitz *et al* 2017).

A major contributor to public misperceptions about climate change is a persistent, decades-long misinformation campaign (McCright and Dunlap 2010). Content analysis of conservative think-tank articles found that arguments casting doubt on climate science are increasing relative to policy arguments (Boussalis and Coan 2016). Climate misinformation impacts public perceptions about climate change in various ways. It decreases acceptance of climate change and lowers confidence about people's understanding (Ranney and Clark 2016). Climate misinformation also disproportionately influences conservatives (Cook *et al* 2017, van der Linden *et al* 2017), contributing to growing polarization over recent decades (McCright and Dunlap 2011). Misinformation cancels out the positive effect of accurate information (McCright *et al* 2016, van der Linden *et al* 2017), implying that accurate science communication is a necessary but insufficient condition to increasing science literacy levels.

Interventions are therefore required to help the public develop resistance to persuasion from misinforming sources. Inoculation theory provides a framework for helping people develop immunity to persuasive misinformation (McGuire and Papageorgis 1961). This approach applies the concept of vaccination to knowledge—it is possible to build resistance to misinformation by exposing people to a weak form of the misinformation. An inoculating text consists of a forewarning of an upcoming persuasion attempt as well as counter-arguments that refute the information.

Inoculation theory however, requires intervention prior to misinformation being received (Bolsen and Druckman 2015). In addition, inoculation theory usually involves the presentation of competing factual claims which if presented after misinformation has solidified subject belief, can result in the backfire effect (Nyhan and Reifler 2010).

We examine a different approach to pre-emptively refuting climate denial misinformation using critical thinking techniques—one that focuses on understanding the logical structure of denialist arguments rather than the truth claims they consist of. Reason-based inoculation is consistent with Compton (2005), who argued that Aristotelian rationality offers a useful framework for inoculating refutations. This approach has been tested experimentally, with an inoculation explaining a misleading technique without including competing factual information demonstrating success in neutralizing the influence of the misinformation (Cook *et al* 2017). This paper introduces key critical thinking concepts and outlines a straightforward process for identifying reasoning errors that allows for people who lack expertise in climate science to confidently reject certain denialist arguments.

2. Understanding arguments

It is important to distinguish between the colloquial use of the term argument to indicate disagreement, often heated, and its formal use here. By argument, we mean a connected series of statements used to establish a definite proposition (Chapman and Python 1989). It is a logical structure that uses the truth of one or more claims (called premises) to establish the truth of some other claim (called the conclusion). In short, arguments give us reasons to believe a claim is true, in a way not linked to the identity, social position, tenor, or rhetorical ability of the person making the claim.

Arguments consist of truth-bearing statements or claims called propositions. A proposition is any meaningful utterance that can be true or false, like 'over 90% of climate scientists believe in anthropogenic climate change' (true), 'New York City is the capital of New York state' (false), or 'it will rain tomorrow' (unknown today). We can contrast propositional statements with non-propositional ones that can not be true or false like 'What is the time?' (interrogative), 'Look out!' (imperative), 'Donuts—yum!' (exclamative). Premises and conclusions must be able to be expressed as propositions. Arguments can answer questions but they can not be constructed with them.

Propositions can be combined in ways such that their truth content gives us information about the truth content of other propositions. If some set of propositions being true (the premises) makes some other proposition (the conclusion) more likely to be true, then we can say that the truth of the premises *supports* the truth of the conclusion. The degree of this support provides us with an important criterion for the judging the quality of an argument.

If the truth of an argument's premises have no bearing on the truth of its conclusion, we say that the argument is a *non sequitur*⁴. For example:

P: I once saw a white swan.

C: My pet is a bird.

If the premises give the conclusion only limited support—if the premises being true makes our belief about the truth of the conclusion only somewhat more likely—we describe the argument as *inductively weak*.

P: I once saw a white swan.

C: All swans are white.

If the premises being true makes our belief about the conclusion's truth much more likely, we describe the argument as *inductively strong*.

P1: I have seen a very large number of swans and they have all been white.

P2: The swans I have seen varied in age, sex, and location.

C: All swans are white.

⁴ Whilst the term *non sequitur* is sometimes used as a synonym for any invalid inference, here we use it in its more common sense as a failure of relevance.

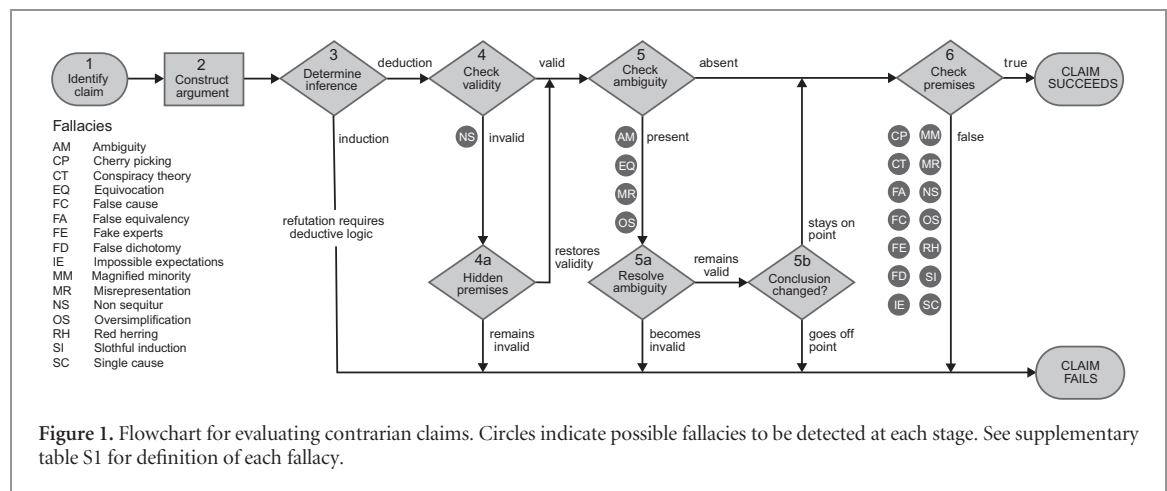


Figure 1. Flowchart for evaluating contrarian claims. Circles indicate possible fallacies to be detected at each stage. See supplementary table S1 for definition of each fallacy.

Sometimes however, the premises of an argument together *logically entail* the truth of the conclusion. This notion of entailment means that it is impossible for the conclusion to be false whilst all the premises are true. When the truth of the premises guarantees or entails the truth of the conclusion, we describe the argument as *deductively valid*.

P1: All swans are white.

P2: My pet is not white.

C: My pet is not a swan.

As anyone who has travelled to Australia may have seen however, not all swans are white. A good argument relies on more than just logical structure—its premises must also be true. These examples highlight two important measures for evaluating the quality of an argument—how strongly the premises support the conclusion (the logical structure) and whether or not the premises are in fact true.

3. Definitive and provisional claims

Whether an argument is deductive or inductive depends on what type of concluding proposition the argument is supposed to establish. Propositions can be made true in different ways. Some are necessarily true: ‘All bachelors are unmarried men’ or ‘Deciduous trees shed their leaves’. Necessarily true propositions are made true by virtue of their meaning.

Contingently true propositions by contrast are true but need not have been—‘Berlin is the capital of Germany’ or ‘The Sydney Swans won the 2012 AFL grand final’. Given the meaning of the terms, it could never have been the case that necessarily true statements were false but contingently true propositions could have been.

Of these contingently true propositions, we might further distinguish between those that are demonstrably true and those that are provisionally true. ‘Donald Trump is the 45th President of the United States’ is demonstrably true because we have observable and verifiable evidence for it. ‘Liberal democracies do not go to war with one another’ by contrast is provisionally true

since there have been no counter-examples to it thus far.

Conclusions with definitive claims require deductive inferences to support them. When the conclusion of our argument is intended to be definitive, that it *is* in fact the case, then no new claim should be able to undermine this. The argument must be indefeasible and the conclusion becomes necessarily true if the premises are all true.

Provisionally true claims do not require such support. Because they are always open to refutation, the arguments that support them need only be defeasible. Inductive inference is therefore indicative of provisionally true claims.

4. Evaluating denialist claims as arguments

Much of the effort to date in refuting denialist arguments has focused on the truth content of particular claims—showing for example that global temperatures are rising (Lewandowsky *et al* 2016) or that there is overwhelming expert consensus that human activity is responsible for much of this change (Cook *et al* 2013). Whilst identifying factual errors is important, research into the ability of misinformation to neutralize factual information indicates that there are limitations to this approach (McCright *et al* 2016). A more comprehensive approach should include identification of flaws in misinforming arguments and explain how the reasons offered do not adequately support their conclusions (Cook *et al* 2017, van der Linden *et al* 2017).

Our contention is that a basic understanding of argumentation is sufficient to refute a large number of climate denialist claims. Applying the introduction to argument structure from section 2, we now outline a process for evaluating climate denialist arguments and apply it to common denialist claims.

Figure 1 outlines a flowchart for evaluating an argument’s cogency. The following sections detail each step in the analysis process. Within the chart, we have also identified locations where certain fallacies of reasoning are typically made. This is to progress work

already done on fallacies found in the denial of climate science (Cook *et al* 2015). Supplementary table S1 available at stacks.iop.org/ERL/13/024018/mmedia includes definitions of the fallacies found in the most common contrarian claims about climate change.

4.1. Identification of claim

We begin by identifying a denialist claim for evaluation (Step 1). For example, a common contrarian claim is 'Earth's climate has changed naturally before, so current climate change is natural.' In constructing and evaluating an argument, it is critical to have clarity about the claim being made. It is also important that the claim is not misrepresented or changed to alter its meaning. As such, we recommend seeking claims made by contrarians and dealing with these as presented.

4.2. Construction of argument

We construct the argument supporting a claim by identifying the set of propositions constituting the premises and conclusion (Step 2). In the case of the claim above the structure would be:

P1: The climate has changed in the past through natural processes

P2: The climate is currently changing

C: The climate is currently changing through natural processes

Having established the argument structure, we next determine the inferential intent of the argument as either *deductive* or *inductive* (Step 3).

4.3. Determine inferential intent

How strongly the conclusion of an argument is formulated determines the type of inferential support required from the premises. Definitive conclusions require the support of deductively valid arguments whilst provisional conclusions require only inductive support. Within science, we find both deductive and inductive arguments. Deductive inferences are common and form the basis of the hypothetico-deductive method:

P1: If my theory is correct, then I will observe this phenomenon.

P2: I did not observe this phenomenon.

C: My theory is not correct.

Yet it is inductive reasoning that underpins the bulk of our empirically derived knowledge:

P1: There is a strong correlation between smoking and cancer in many studies that controlled for numerous possible confounders.

P2: There is a plausible explanatory framework for why smoking would cause cancer.

C: Smoking very likely causes cancer.

Whilst the conclusions of inductive inferences are often stated definitively in everyday language e.g. 'smoking causes cancer', they are not intended to be definitive. The majority of scientific claims are open to adjustment, correction and even refutation. The ability to state the conditions under which a theory can be falsified, and hence refuted, is an important

determiner for discriminating science from pseudo-science (Popper 1957).

Climate denialist claims however, are typically definitive, taking a form such as 'human activity is *not* the cause of current climate change' rather than 'human activity *might not* be the primary cause of current climate change'. Similar definitive denialist claims are common (Elsasser and Dunlap 2013)

- 'Climate change is not happening.'
- 'There is no empirical evidence that humans are causing global warming.'
- 'There is no scientific consensus that human-caused climate change is occurring.'

If we are to accept these denialist claims, then like any definitive conclusion, they must be supported by a deductively valid argument.

Of course, not all denialist claims are stated definitively, such as arguments that exaggerate the role of scientific uncertainty (Freudenburg and Muselli 2013, McCright and Dunlap 2000). As such they only require inductive support. In cases where non-definitive denialist claims conflict with non-definitive claims of climate science, then we need some other method to reconcile competing inductive arguments. How we should reconcile competing inductive inferences is outside the scope of this paper.

If the denialist intent is to support a definitive claim through a deductive argument, then the next step in the process is to check for validity. If the intent is to produce a claim which is not definitive because it relies on an inductive argument, then the attempted refutation of anthropogenic global warming (AGW) has already failed.

4.4. Check for validity

If the argument in question is deductive in intent, it is then checked for validity (Step 4). An argument in support of definitive claims must be deductively valid, for without this degree of logical entailment the truth of the premises gives us insufficient reason to accept the truth of the conclusion.

The claim that 'Human activity is not causing climate change' is often supported with the idealised argument below.

P1: A previous change in climate was not the result of human activity.

P2: The climate is currently changing.

C: The current change in climate is not the result of human activity.

There is a variety of formal methods available to prove that an argument is valid, such as truth tables, trees, or tableau. Unfortunately, formal methods require a degree of training in formal logic to use and therefore it is usually much simpler to demonstrate an argument is invalid by use of a parallel argument.

Parallel arguments use the same logical structure as the target argument but instantiate it in such a way that

the conclusion is obviously false. In a valid argument it is impossible for the conclusion to be false whilst all the premises are true. Parallel arguments identify a clear counter example and show that an argument is not valid. Parallel arguments have strong pedagogical value because they use concrete examples, which are closer to our own experience than abstract reasoning (Juthe 2009). For example:

P1: A previous swan death was not the result of human activity.

P2: This swan is dying.

C: This swan dying is not the result of human activity.

It is clear that the conclusions do not *necessarily* follow from the premises and the arguments are therefore invalid. Just because something *can* be a cause, does not *make* it a cause in any particular instance. The conclusion is not justified by the reasons given, so we must either reject the conclusion or revise it so the argument is valid as follows:

P1: A previous change in climate was not the result of human activity.

P2: The climate is currently changing.

C: The current change in climate *may* not be the result of human activity.

(Note that now the conclusion has been changed to make the argument valid, it is no longer definitive and the attempt at refuting AGW fails. This will be explained further in section 4.5).

4.4.1. Identify hidden premises

If the argument is determined to be invalid, we next attempt to identify any hidden premises that might be added to the argument to make it logically valid (Step 4a). Arguments often rely on unstated assumptions and implied conclusions to be valid. These hidden premises must be made explicit for the argument to become valid. Another common denialist argument against human-caused global warming can be articulated as follows:

P1: There is no empirical evidence that humans are causing global warming.

[P2 (Hidden): If there is no empiric evidence for something, then it is not happening.]

C: Humans are not causing global warming.

By making clear the hidden premise, we can make this argument valid. We can do the same with the first argument from section 4.4. Rather than reject the conclusion because it was not adequately supported by the premise or change the conclusion's modality from *necessarily* not the cause to *possibly* not the cause, we can keep the stronger conclusion and add a new premise to make the argument valid.

P1: A previous change in climate was not the result of human activity.

P2: The climate is currently changing.

P3: (Hidden) If something was not the cause in the past, it will not be the cause in the future.

C: The current change in climate is not the result of human activity.

Now both arguments are valid and the conclusions would be true, *if all of the premises were in fact true*. Whether the an argument should convince us is dependent on both the strength of the logical structure and the premises actually being true.

4.5. Check for ambiguity

If an argument is logically valid (or we added hidden premises to create validity), we next check for ambiguity. A common form of ambiguity is equivocation—when the same word or phrase is used with two different meanings (Step 5). Consider now the following trope:

P1: Nothing is better than eternal happiness (true).

P2: A ham sandwich is better than nothing (true).

C: A ham sandwich is better than eternal happiness (entailed from 1 and 2).

Obviously, the conclusion is false even though the argument is valid and the premises (when stated in isolation) are (arguably) true. The argument however, relies on ambiguous language, or equivocation, regarding the term 'nothing'. In premise 1, we mean no thing is better than eternal happiness; in premise 2 we mean having a ham sandwich is better than not having one. Once we remove the equivocation, the argument becomes invalid (indeed a non sequitur) and we can reject the conclusion.

Some climate denialist arguments rely on similar equivocation. Consider the following variation of the 'past climate change' contrarian claim:

P1: Natural process and human activity can both cause climate change.

P2: Climate change is currently occurring.

C: Human activity is not necessary to explain current climate change.

The syntax conveys the impression that the argument is valid, but it is not. The term 'climate change' referred to in Premise 1 and Premise 3 do not have the same meaning, since the rate of change is different in each. If equivocation exists, we resolve it by either clarifying the argument's language or adding premises to resolve any ambiguity (Step 5a). In this example, Premise 3 is amended to clarify the rate of current climate change. Once Premise 3 is amended, the argument becomes invalid:

P1: Natural processes have caused climate change in the past.

P2: Human activity can cause climate change.

P3: *The climate is currently changing at a much more rapid rate than can be explained by natural processes.*

C: Human activity is not necessary to explain current climate change.

We can attempt to restore validity by accepting the premises and seeing what conclusion must follow from them (Step 5b):

P1: Natural processes have caused climate change in the past.

P2: Human activity can cause climate change.

P3: The climate is currently changing at a much more rapid rate than can be explained by natural processes.

C: Human activity is necessary to explain current climate change.

If the resolution resulting from the amendment of any premises renders the argument invalid, then the contrarian claim is considered to have failed in refuting AGW. If the argument remains valid after resolution, then we see whether the conclusion has changed as part of that validation process. If the conclusion is off-point relative to the original conclusion, then the contrarian claim has failed. In this example, the conclusion has changed such that natural causation of climate change has been ruled out, coming to the opposite conclusion to the original version of the argument. Importantly, in rewriting the premises to avoid equivocation, the conclusion has *necessarily* changed—it is not something that was arrived at arbitrarily.

4.6. Check premises for truth or plausibility

If the conclusion stays on-point or the argument has not been ruled out in earlier steps (i.e. it is deductive, valid, and with no equivocation), then the final step is to determine the truth of the premises (Step 6). A major advantage of the approach we are proposing in this paper is that evaluating climate denialist claims as arguments allows a general reader to judge the veracity of many claims about science without the need for expertise in climate science (and allow non-expert recipients of a refutation to comprehend why a claim is false). Yet as we have just outlined, good arguments require more than the conclusion being true *if* the premises were all true, they also require the premises to *be* true. So then how do we evaluate the truth of the premises without expertise in climate science?

The simple answer is that we often do not need to. Denialist arguments, once made valid by articulating any required suppressed premises, will tend to rely on demonstrably false or implausible general claims. Take for example, the assumed premise in the last argument ‘If something was the cause in the past, it will be the cause in the future’. This claim is highly implausible for any effect that has multiple possible causal mechanisms. So too, the claim ‘If there is no empiric evidence for something, then it is not happening’ which mistakes an absence of evidence for evidence of absence.

5. Discussion

Psychological research indicates that explaining the techniques employed to distort scientific information is an important component of neutralising misinformation. This paper lays out a template for systematic deconstruction and assessment of denialist claims, in order to identify false premises and fallacious reasoning. We explicitly restrict ourselves to deductive

claims that purport to refute mainstream climate science. However, inductive arguments have also been employed in order to cast doubt on the reality of climate change, usually by misrepresenting or exaggerating the nature of scientific uncertainty (Freudenburg and Muselli 2013, McCright and Dunlap 2000). Assessment of inductive denialist claims from a critical thinking perspective is an area of future research.

Our reason-based approach to refuting climate science misinformation could be used as a specific application of current inoculation theory. Typically, inoculation interventions are information-based, containing facts that counter the misleading information. For example, van der Linden *et al* (2017) countered the Global Warming Petition Project by communicating the 97% scientific consensus on human-caused global warming, as well as explaining specific misleading elements of the Petition Project. In contrast, Cook *et al* (2017) used a reason-based inoculation against the Global Warming Petition Project that refrained from mentioning the 97% consensus or the Petition Project. Instead, the explanation of the general technique of fake experts was successful in inoculating participants against the negative influence of the Petition Project. Further research into this approach is recommended, directly comparing its efficacy to information-based inoculations, measuring how susceptible reason-based interventions are subject to decay effects, and exploring whether reason-based inoculations can convey resistance against multiple arguments.

Supplementary table S2 includes analysis of 42 common climate myths that feature deductive arguments, taken from the Massive Open Online Course (MOOC), *Denial101x: Making Sense of Climate Science Denial* (Cook *et al* 2015) and employing the critical thinking approach explained in the MOOC *Meta101x: Philosophy and Critical Thinking* (Brown and Ellerton 2015). Our analysis found that all of the 42 denialist claims failed to falsify anthropogenic global warming. However, these claims are effective in misinforming the public and decreasing climate literacy. Consequently, refuting and neutralizing the influence of this misinformation is necessary.

Social media presents one potent option for practically deploying resources of this type to neutralize misinformation, using an approach described as ‘technocognition’: an approach that incorporates principles from behavioural economics, cognitive psychology, and philosophy in the design of information architectures (Lewandowsky *et al* 2017). Misconception-based learning, applied in the classroom, is another powerful and practical model for deploying inoculation content (McCuin *et al* 2014). While there have been efforts to apply this approach to climate education (Bedford 2010, Cook *et al* 2014), and development of resources (Bedford and Cook 2016), there is in general a dearth of misconception-based learning resources for educators (Tippett 2010). Consequently, this research is designed to act as a

building block for developing educational material that teaches critical thinking through the examination of misinformation and evaluation of arguments.

This work may also serve as a template for analysis of misinformation on other topics besides climate change. Misinformation about vaccination, evolution, and other scientific topics have negative impacts on science literacy and can lead to severe societal consequences. Consequently, application of our process for evaluating misleading claims may be useful in developing resources for scientists, communicators, and educators seeking to reduce the influence of misinformation across a variety of issues.

ORCID iDs

John Cook  <https://orcid.org/0000-0001-8488-6766>

Peter Ellerton  <https://orcid.org/0000-0002-6588-376X>

David Kinkad  <https://orcid.org/0000-0001-5396-8099>

References

- Anderegg W R L, Prall J W, Harold J and Schneider S H 2010 Expert credibility in climate change *Proc. Natl Acad. Sci. USA* **107** 12107–9
- Bedford D 2010 Agnotology as a teaching tool: learning climate science by studying misinformation *J. Geogr.* **109** 159–65
- Bedford D and Cook J 2016 *Climate Change: Examining the Facts* (Santa Barbara, CA: ABC-CLIO)
- Bolsen T and Druckman J N 2015 Counteracting the politicization of science *J. Commun.* **65** 745–69
- Boussalis C and Coan T G 2016 Text-mining the signals of climate change doubt *Glob. Environ. Change* **36** 89–100
- Brown D and Ellerton P 2015 Philosophy and Critical Thinking edX (www.edx.org/course/philosophy-critical-thinking-uxq-meta101x-1)
- Carlton J S, Perry-Hill R, Huber M and Prokopy L S 2015 The climate change consensus extends beyond climate scientists *Environ. Res. Lett.* **10** 094025
- Chapman G and Python M 1989 *The Complete Monty Python's Flying Circus: All the Words* vol 2 (London: Pantheon)
- Compton J 2005 Comparison, contrast, and synthesis of aristotelian rationality and inoculation *J. Speech Theatre Assoc. Mo.* **35** 1–23
- Cook J, Bedford D and Mandia S 2014 Raising climate literacy through addressing misinformation: case studies in agnotology-based learning *J. Geosci. Educ.* **62** 296–306
- Cook J, Lewandowsky S and Ecker U 2017 Neutralizing misinformation through inoculation: exposing misleading argumentation techniques reduces their influence *PLoS ONE* **12** e0175799
- Cook J, Nuccitelli D, Green S A, Richardson M, Winkler B, Painting R, Way R, Jacobs P and Skuce A 2013 Quantifying the consensus on anthropogenic global warming in the scientific literature *Environ. Res. Lett.* **8** 024024
- Cook J *et al* 2016 Consensus on consensus: a synthesis of consensus estimates on human-caused global warming *Environ. Res. Lett.* **11** 048002
- Cook J *et al* 2015 Denial101x: making sense of climate science denial edX (<http://edx.org/understanding-climate-denial>)
- Doran P T and Zimmerman M K 2009 Examining the scientific consensus on climate change *Eos, Trans. Am. Geophys. Un.* **90** 22–3
- Elsasser S W and Dunlap R E 2013 Leading voices in the denier choir: conservative columnists' dismissal of global warming and denigration of climate science *Am. Behav. Sci.* **57** 754–76
- Flood A 2016 Post-truth named word of the year by Oxford Dictionaries *Guardian* (www.theguardian.com/books/2016/nov/15/post-truth-named-word-of-the-year-by-oxford-dictionaries)
- Flood A 2017 Fake news is very real word of the year for 2017 *Guardian* (www.theguardian.com/books/2017/nov/02/fake-news-is-very-real-word-of-the-year-for-2017)
- Freudenburg W R and Muselli V 2013 Reexamining climate change debates: scientific disagreement or scientific certainty argumentation methods (SCAMs)? *Am. Behav. Sci.* **57** 777–95
- Juthe A 2009 Refutation by parallel argument *Argumentation* **23** 133
- Leiserowitz A, Maibach E, Roser-Renouf C, Rosenthal S and Cutler M 2017 Climate change in the American mind: May 2017 Report (New Haven, CT: Yale Program on Climate Change Communication)
- Lewandowsky S, Ecker U K H and Cook J 2017 Beyond misinformation: understanding and coping with the post-truth era *J. Appl. Res. Mem. Cogn.* **6** 353–69
- Lewandowsky S, Ecker U K, Seifert C M, Schwarz N and Cook J 2012 Misinformation and its correction continued influence and successful debiasing *Psych. Sci. Pub. Interest* **13** 106–31
- Lewandowsky S, Risbey J S and Oreskes N 2016 The 'pause' in global warming: turning a routine fluctuation into a problem for science *Bull. Am. Meteorol. Soc.* **97** 723–33
- McCright A M and Dunlap R E 2000 Challenging global warming as a social problem: an analysis of the conservative movement's counter-claims *Soc. Probl.* **47** 499–522
- McCright A M and Dunlap R E 2010 Anti-reflexivity: the American conservative movement's success in undermining climate science and policy *Theor. Cult. Soc.* **27** 100–33
- McCright A M and Dunlap R E 2011 The politicization of climate change and polarization in the American public's views of global warming 2001–2010 *Sociol. Q.* **52** 155–94
- McCright A M, Charters M, Dentzman K and Dietz T 2016 Examining the effectiveness of climate change frames in the face of a climate change denial counter-frame *Top. Cogn. Sci.* **8** 76–97
- McQuinn J L, Hayhoe K and Hayhoe D 2014 Comparing the effects of traditional vs. misconceptions-based instruction on student understanding of the greenhouse effect *J. Geosci. Educ.* **62** 445–59
- McGuire W J and Papageorgis D 1961 The relative efficacy of various types of prior belief-defense in producing immunity against persuasion *Public Opin. Q.* **26** 24–34
- Nyhan B and Reifler J 2010 When corrections fail: the persistence of political misperceptions *Polit. Behav.* **32** 303–30
- Popper K 1957 Philosophy of science *British Philosophy in the Mid-Century* ed C A Mace (London: George Allen and Unwin)
- Ranney M A and Clark D 2016 Climate change conceptual change: scientific information can transform attitudes *Top. Cogn. Sci.* **8** 49–75
- Tippett C D 2010 Refutation text in science education: a review of two decades of research *Int. J. Sci. Math. Educ.* **8** 951–70
- van der Linden S, Leiserowitz A, Rosenthal S and Maibach E 2017 Inoculating the public against misinformation about climate change *Glob. Chall.* **1** 1600008
- World Economic Forum 2014 Outlook on the global agenda 2014 Report (<http://reports.weforum.org/outlook-14/view/top-ten-trends-category-page/10-the-rapid-spread-of-misinformation-online>) (Accessed: 12 May 2014)