Closing the "consensus gap" by communicating the scientific consensus on climate change and countering misinformation

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Abstract

There is a consensus among climate scientists that humans are causing global warming. However, the general public think there is significant scientific disagreement about human-caused global warming. This misconception, and in particular the difference between expert and public opinion—the "consensus gap"—has societal consequences, as perceived consensus is a gateway belief influencing a range of climate attitudes including policy support. One contributor to the consensus gap is misinformation, which is designed to manufacture doubt about the level of scientific agreement on anthropogenic global warming (AGW). This multi-paper thesis explores the psychology of consensus, testing experimentally the effect of consensus information and conversely, the influence of misinformation designed to cast doubt on the consensus.

I found that overall, consensus information is effective in increasing acceptance of AGW. However, among a small proportion of the public with strong conservative beliefs, the provision of consensus information can be counterproductive; this could contribute to the persistence of the rejection of climate science. I also found that an effective approach to neutralising the influence of misinformation is inoculation against misinformation techniques. As well as conduct research into the psychology of consensus, this thesis documents my efforts to summarise and communicate the body of research into misinformation and consensus, encouraging more evidence-based science communication. Lastly, I outline the potential for practical application of my research in the form of agnotology-based learning, which teaches scientific concepts through the refutation of misconceptions. Several methods of applying agnotology-based learning include Massive Open Online Courses (MOOCs) and developing educational resources structured to facilitate this teaching approach.

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I would like to thank a number of people who have made completion (indeed survival) of this doctorate possible. Some of the papers I have co-authored over the course of this doctorate have attracted an intense amount of attention, which has resulted in a number of attacks on my research. The support and assistance of a number of people through this tumultuous period has been valuable and deeply appreciated.

First and foremost, I wish to thank my supervisors Stephan Lewandowsky and Ullrich Ecker. Throughout this doctorate, Stephan was always available for feedback, advice and guidance. Stephan and Ulli, in collaboration with the research lab at the University of Western Australia, are the hub of much of the current-edge research into misinformation. It was an honour to build on the research being conducted there.

It has also been a pleasure collaborating with my co-supervisor Ullrich Ecker. His advice, death threats, and friendship throughout the course of my PhD have been deeply appreciated, despite his research efforts to undermine most of the backfire effects listed in the Debunking Handbook. I must also thank Mark Hurlstone for his generous feedback and Charles Hanich for his assistance with Qualtrics and navigating the UWA systems.

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Throughout this journey and prior to this doctorate, I have been honoured to work with the passionate and talented volunteer team at Skeptical Science. The impact that this team, a collection of volunteers working in their spare time, sharing a passion for climate communication, is extraordinary – our research has been cited by Presidents, Prime Ministers, mainstream media and throughout the scientific community. I must specially mention my co-authors Dana Nuccitelli, Sarah Green, Mark Richardson, Baerbel Winkler, Rob Painting, Robert Way, Peter Jacobs and Andrew Skuce. More broadly, the Skeptical Science community has been a strong and constant source of support, knowledge and wisdom over the years.

I was delighted to discover a kindred spirit in Daniel Bedford whose pioneering work in raising climate literacy through agnotology-based learning has inspired me to follow suit. Scott Mandia also joined us in these efforts, as well as the co-authoring of a paper on agnotology-based learning. Both Daniel and Scott are excellent college professors, as indicated by their ratings on the Rate My Professor website.

Mid-way through this doctorate, I undertook the development of a Massive Open Online Course (MOOC). On the plus side, this project was essentially an application of the research I had conducted for my PhD (on the negative side, it delayed the completion of this doctorate by about a year). The project was an immense undertaking and would not have been possible without the dedicated work and support from MOOC coordinator Tanya Dodgen and MOOC designer Carrie Finn. I also must express my appreciation of the talented folk at UQx – Matt Peterson, Shannon O'Brien and Daniel Greenup.

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Table of Contents

Papers Included in this Thesis

Paper 1: Published (Chapter 2)

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

Paper 2: Published (Chapter 2)

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Paper 3: Published (Chapter 3)

Cook, J. & Lewandowsky, S. (2016). Rational irrationality: Modeling climate change belief polarization using Bayesian networks. *Topics in Cognitive Science*. *8*(1), 160-179.

Paper 4: Published (Chapter 4)

Lewandowsky, S., Ecker, U. K. H., Seifert, C. M., Schwarz, N., & Cook, J. (2012). Misinformation and its correction: Continued influence and successful debiasing. *Psychological Science in the Public Interest*, *13*, 106-131.

Paper 5: Published (Chapter 4)

Cook, J., Ecker, U. & Lewandowsky, S. (2015). Misinformation and how to correct it, *Emerging Trends in the Social and Behavioral Sciences*. Robert Scott and Stephen Kosslyn (Eds.), Hoboken, NJ: John Wiley and Sons.

Paper 6: Published (Chapter 4)

Cook, J. (in press). Countering climate science denial and communicating scientific consensus. In M. Nisbett (Ed.), *Oxford Encyclopedia of Climate Change Communication*. London: Oxford University Press.

Paper 7: Published (Chapter 5)

Cook, J., Lewandowsky, S., & Ecker, U. K. H. (2016, submitted). Neutralising misinformation through inoculation: Exposing misleading argumentation techniques reduces their influence.

Paper 8: Published (Chapter 5)

Lewandowsky, S., Cook, J., & Lloyd, E. A. (2016, submitted). The `Alice in Wonderland' Mechanics of the Rejection of (Climate) Science: Simulating Coherence by Conspiracism.

Paper 9: Published (Chapter 6)

Cook, J., Bedford, D. & Mandia, S. (2014). Raising climate literacy through addressing misinformation: Case studies in agnotology-based learning. *Journal of Geoscience Education*, *62*(3), 296-306.

Statement of Candidate Contribution to Included Papers

Paper 1: 50% contribution (Chapter 2)

Candidate contributed to design of rating scheme, collected & converted Web of Science data, programmed the web-based rating system, contributed to abstract rating, conducted the invitation of author self-ratings, contributed to the literature review, undertook primary manuscript preparation and contributed to analysis and revisions. Co-authors contributed to literature review, ratings, author email collection, analysis and revisions.

Paper 2: 40% contribution (Chapter 2)

Candidate prepared and revised manuscript, including synthesis of existing research. Co-authors contributed to editing and literature review.

Paper 3: 80% contribution (Chapter 3)

Candidate designed and ran experiments, completed literature review, designed and programmed Bayes Net computational model, undertook primary manuscript preparation and revisions. Stephan Lewandowsky supervised the project, providing guidance and feedback on the experiment design, model development, analysis, and manuscript preparation.

Paper 4: 15% contribution (Chapter 4)

Candidate prepared section on online misinformation and provided additional contributions and feedback on the manuscript preparation.

Paper 5: 80% contribution (Chapter 4)

Candidate prepared and revised manuscript. Co-authors contributed to preparation and provided additional contributions during revision.

Paper 6: 97% contribution (Chapter 4)

Candidate prepared and revised manuscript. Comments supplied by Stephan Lewandowsky, Ullrich Ecker and members of the Skeptical Science team.

Paper 7: 70% contribution (Chapter 5)

Candidate designed and ran experiments, completed literature review, undertook primary manuscript preparation and revisions. Stephan Lewandowsky supervised the project. Stephan Lewandowsky and Ullrich Ecker provided guidance and feedback on the experiment design, analysis and manuscript preparation.

Paper 8: 30% contribution (Chapter 5)

Candidate contributed to manuscript preparation and collated pairs of incoherent claims along with examples. Co-authors prepared and provided feedback on the manuscript.

Paper 9: 70% contribution (Chapter 6)

Candidate completed literature review, undertook primary manuscript preparation and revisions. Scott Mandia and Daniel Bedford wrote the sections on Case Study 1 and 2 and provided additional contributions and feedback on the manuscript preparation.

Each author has given permission for all work to be included in this thesis.

[redacted]

2 May 2016

John Cook (candidate) Date

[redacted]

Stephen Lewandowsky (Coordinating supervisor) Date

Chapter 1
Introduction

Among publishing climate scientists, there is overwhelming agreement that humans are causing global warming, primarily through the burning of fossil fuels (Anderegget al., 2010; Carlton et al., 2015; Cook et al., 2013; Cook et al., 2016; Doran & Zimmermann, 2009; Oreskes, 2004; Stenhouse et al., 2014; Verheggen et al., 2014). This consensus is mirrored in the reports of the Intergovernmental Panel on Climate Change, which have emphatically affirmed the human contribution to recent global warming as well as the negative societal consequences of unmitigated climate change (Qin et al., 2014). The policy implication of this scientific reality is the imperative to reduce carbon dioxide emissions in order to avoid the worst impacts of climate change. However, public support for policies that mitigate future climate impacts is low among certain demographics (e.g., U.S. Republicans, Leiserowitz et al., 2015).

One contributor to the lack of public support is low levels of climate literacy. A number of public surveys have observed low levels of understanding of climate science and low awareness of the scientific consensus on climate change (Leiserowitz et al., 2015). Psychological research indicates that low perceived consensus influences the degree of support for climate action (Ding et al., 2011; McCright, Dunlap, Xiao, 2013; van der Linden et al., 2015). More broadly, understanding of the causes of climate change correlates with policy support (Bedford, 2015; Guy, Kashima, Walker, & O'Neill, 2014; Shi, Visschers, Siegrist, & Arvai, 2016). Consequently, improving climate literacy can play an important role in removing a key roadblock to progress on climate mitigation.

Psychological research has a great deal to offer in developing effective interventions designed to improve climate literacy. Which climate concepts are most influential on climate attitudes? What are the most efficacious messages? What potential factors might reduce the effectiveness of climate communication?

A number of studies have found that perceived consensus is a “gateway belief”, influencing acceptance of the existence of climate change, belief in human causation of climate change and climate policy support (Ding, Maibach, Zhao, Roser-Renouf, & Leiserowitz, 2011; McCright, Dunlap, & Xiao, 2013; van der Linden, Leiserowitz, Feinberg, & Maibach, 2015). However, the public have low perceived consensus, with less than 10% of Americans aware that over 90% of climate scientists agree on human-caused global warming (Leiserowitz, Maibach, Roser-Renouf, Feinberg, & Rosenthal, 2015). This gap between public perception and the 97% reality is known as the “consensus gap” (Cook & Jacobs, 2014), and constitutes a significant roadblock delaying public support for climate action.

There are several contributors to this gap. First, representative surveys have found that perceived consensus varies significantly depending on political beliefs, with conservatives showing a lower perceived consensus relative to liberals (Leiserowitz et al, 2015). The relationship between political beliefs and beliefs about climate change has been attributed to aversion to proposed policy solutions to human-caused climate change (Campbell & Kay, 2014). A commonly-suggested policy is regulation of polluting industries, an approach which is unwelcome to supporters of free, unregulated markets. As a consequence, political ideology is one contributor to the consensus gap, causing some people to have a lower perception of expert agreement on human-caused global warming.

Second, even among liberals, who possess no political bias predisposing them to oppose a scientific consensus on climate change, perceived consensus is still quite low. This indicates that lack of awareness of the scientific consensus is another contributor to the consensus gap. This lack of awareness could arise from two possible influences – a deficit of information or a surplus of misinformation.

Misinformation has been shown to be effective in reducing climate literacy (McCright, Charters, Dentzman, & Dietz, 2016; Ranney & Clark, 2016). A prolific source of misinformation is conservative think-tanks which disseminate their claims against climate science through contrarian books (Jacques, Dunlap, & Freeman, 2008) and media appearances (Boykoff, 2013; Painter & Gavin, 2015). Another source of misinformation are scholarly papers disputing anthropogenic global warming, which have consistently been shown to be methodologically flawed (Abraham et al., 2014; Benestad et al., 2015). Casting doubt on the scientific consensus on anthropogenic global warming has been observed to be one of the most common strategies of opponents of climate action (Elsasser & Dunlap, 2012).

Further, misinformation about the consensus has been observed to cancel out the positive effect of consensus information (van der Linden, Leiserowitz, Rosenthal, Feinberg, & Maibach, in revision). Consequently, misinformation is problematic in that it reduces climate literacy and neutralises the positive effect of accurate scientific information.

Undoing the negative impact of misinformation is a problematic exercise. There are a number of psychological processes that make debiasing difficult, and even counter-productive in certain situations. For example, people continue to be influenced by misinformation even when they accept and recall a retraction (Ecker, Lewandowsky, &

Tang, 2010). Refutations have also been observed to reinforce misconceptions in some cases, known as a “backfire” or “boomerang” effect (Lewandowsky et al., 2012).

Psychological research points to several key elements to an effective refutation of misinformation. First, people should be warned beforehand before being exposed to the myth being retracted (Ecker et al., 2010). Second, a key element to an effective retraction is a factual alternative that replaces the gap created by the refutation (Johnson & Seifert, 1994). Elements of a successful alternative explanation include explanations of the causal links originally filled by the myth, why the misinformation was believed in the first place and the motivation behind the misinformation.

In summary, there is a growing body of research investigating the corrosive impact of misinformation and experimentally testing effective methods of refutation. This multi-paper thesis applies misinformation research to the issue of climate change, and builds on the extant psychological research with a number of experiments. What factors contribute to low levels of climate literacy, particularly as it pertains to perception of the scientific consensus? What role does misinformation play in maintaining the gap between perceived scientific agreement and the 97% consensus? What insights can cognitive psychology provide in how people update their beliefs in response to consensus messaging? This thesis addresses the question: how do we explain the consensus gap, and how can we close it?

Chapter 2 features a published paper that quantified the level of scientific agreement in peer-reviewed climate papers, finding that 97% of climate papers stating a position on AGW endorsed the consensus (Cook et al., 2013). This chapter also includes a follow-up study co-authored with authors of six other consensus studies, synthesising the research into consensus (Cook et al., 2016).

Establishing that there is a scientific consensus on AGW is one thing; it is another thing to effectively communicate the consensus. In Chapter 3, I outline the development of a computational cognitive model that simulates belief updating in response to consensus information. Fitting the model to experimental data, I was able to glean insights into the cognitive processes at play when participants respond to information that is perceived to be relevant to their worldview. This is especially pertinent in the case of people with strong conservative values, who responded to consensus information with a decrease in acceptance of climate change. My computational model indicated that this contrary response amongst those with strong free market support was driven by active distrust of climate scientists.

This result indicates that there is a limit to what climate communication can achieve amongst the small proportion of the population who are dismissive of climate science. The persistence of dismissive attitudes about climate change implies that the generation of misinformation about climate science is also expected to persist. This result is consistent with an analysis that reported that conservative think-tanks continue to generate misinformation against climate science (Boussalis & Coan, 2016).

The practical consequences of this research are relevant for scientists and communicators who are working on contentious issues such as climate change, vaccinations, or genetically-modified organisms (GMO), where misinformation is prevalent. Raising awareness of the best-practices implied by psychological research into misinformation, including my own results, is an important step towards the scientific community adopting a more evidence-based approach to science communication. Chapter 4 contains three papers summarising the psychological research into misinformation.

Lewandowsky et al. (2012) was the first comprehensive literature review of psychological research into the impact and refutation of misinformation. Cook, Ecker, & Lewandowsky (2015) looked at cutting edge research into misinformation, while anticipating future lines of research. Cook (in press) was an invited chapter in the Oxford Encyclopedia of Climate Change Communication, that reviewed both the literature on misinformation as well as the issue of communicating the scientific consensus on climate change.

The issue of scientific consensus has generated some controversy within scholarly circles, with several researchers questioning the value of consensus messaging or even suggesting it is counterproductive (Kahan, 2015; Pearce, Brown, Nerlich, & Koteyko, 2015). However, these objections fail to take into account the extant literature on consensus messaging. Cook (in press) outlines the evidence for the efficacy of consensus messaging while responding to common objections.

One potential strategy in response to misinformation is inoculation – the practice of exposing people to a weak form of misinformation in order to build resistance to subsequent exposures to misinformation. Chapter 5 describes my research into the impact of misinformation, as well as interventions whose purpose is to neutralise the influence of misinformation. My research found that inoculating messages that pre-emptively explain the techniques of science denial are effective in neutralising the influence of misinformation.

A practical approach to implementing inoculation is in the classroom. Several decades of educational research have examined the teaching approach of misconception-based learning (McCuin, Hayhoe, & Hayhoe, 2014). Lessons that explicitly refute misconceptions have been observed to achieve higher and long-lasting learning gains relative to lessons that teach the science without reference to misconceptions. This teaching approach has already been applied by educators such as Daniel Bedford, who coined the term “agnotology-based learning” (Bedford, 2010).

Chapter 6 reviews the concept of agnotology-based learning and describes a case study of this teaching approach (Cook, Bedford, & Mandia, 2014). In this paper, I also use The Consensus Project (described in Chapter 2) as a real-world example of climate communication based on agnotology-based learning principles. Complementing this work, I developed a Massive Open Online Course (MOOC), *Making Sense of Climate Science Denial*, which teaches the fundamental concepts of climate change while simultaneously refuting common climate misconceptions. I also co-authored a university textbook with Daniel Bedford, *Climate Change: Myths and Realities*, developed as a resource for educators wishing to adopt agnotology-based learning in their classroom.

In sum, my research over the course of this doctorate adopted a multi-disciplinary approach, studying physical science, computational cognitive modelling and educational research. This research was united by the question “how do we close the consensus gap in the presence of the organized dissemination of misinformation?” The conclusion of my research was two-fold: communicating the 97% scientific consensus and inoculating against misinformation that casts doubt on the consensus are both keys to closing the consensus gap. These principles that I narrowly applied to the issue of consensus can also be generalised to be relevant to other areas of science communication.

Chapter 2

The scientific consensus on anthropogenic global warming

This chapter is presented in the format of two journal article manuscripts.

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

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

Foreword

The seminal work in quantifying the scientific consensus on human-caused global warming was published by Oreskes (2004). Oreskes analysed 908 scientific articles matching the Web of Science search term 'global climate change', from 1993 to 2003, and found that none of the articles rejected anthropogenic global warming. This research was featured in Al Gore's Academy Award winning film *An Inconvenient Truth*.

Subsequent research has reaffirmed the overwhelming scientific consensus on climate change. A survey of Earth scientists found that among actively publishing climate scientists, 97% agreed that humans were significantly raising global temperature (Doran & Zimmerman, 2009). An analysis of public statements about climate change found that among signatories who had published peer-reviewed climate research, 97% agreed with the consensus position (Anderegg, Prall, Harold, & Schneider, 2010).

This chapter includes Cook et al. (2013), which furthered Oreskes' methodology by identifying papers that either endorsed, rejected or expressed no position on AGW. Our analysis rated the abstracts of 12,464 papers matching the search "global climate change" or "global warming" from 1991 to 2011 in the Web of Science database (Cook et al., 2013). We also invited the authors of the papers to rate their own research, in order to obtain an independent measure of consensus. Our abstract rating found 97.1% agreement that humans are causing global warming amongst climate abstracts stating a position on AGW. The independent author self-ratings found 97.2% agreement with regards to climate papers self-rated as stating a position on AGW.

This finding of 97% consensus is consistent with a number of other studies that had previously found an overwhelming consensus among climate scientists (Doran, 2009;

Anderegg et al, 2010) as well as studies that would subsequently go on to find a strong consensus after our publication (Carlton et al., 2015; Verheggen et al., 2014). However, among the general public, there is little awareness of the strength of scientific agreement (Leiserowitz et al., 2015). Consequently, our study received a significant amount of media attention, including a number of tweets by President Obama (Cook, Bedford, & Mandia, 2014).

The research also received a great deal of criticism from contrarians who rejected the scientific consensus on AGW. Some of these criticisms were published in scholarly journals (Dean 2015; Legates, Soon, Briggs, & Monckton, 2013; Tol, 2014; Tol, 2016), necessitating a scholarly response (Cook et al., 2014; Cook & Cowtan, 2015; Cook et al., 2016).

This chapter also includes Cook et al. (2016), which was a response to the claim in Tol (2016) that Cook et al. (2013) was an outlier compared to other consensus studies. Co-authored by authors of six other consensus studies, Cook et al. (2016) found that Cook et al. (2013) was consistent with existing consensus estimates and that Tol (2016) had misrepresented those other studies.

While there has been a significant amount of scholarly interest in the consensus estimate in Cook et al. (2013), consensus messaging has also become a salient issue due to the high profile of the research. Cook, Bedford, & Mandia (2014) examines the communication strategy used to promote the research results of Cook et al. (2013), as well as two other college-based case studies in agnotology-based learning. Other researchers conducted their own research into the efficacy of our communication approach, using the website design of theconsensusproject.com and accompanying social media infographics as research material (Green, 2015; van der Linden, Leiserowitz, Feinberg, & Maibach, 2014). Van der Linden et al. (2014) found retroactively that the pie-chart imagery was one of the most effective ways of communicating the consensus. There were also criticisms of our communication campaign, questioning its efficacy and appropriateness of consensus messaging as a climate communication approach, both in social media and in scholarly journals (Kahan, 2015; Pearce, Brown, Nerlich, & Koteyko, 2015).

The efficacy of consensus messaging is an empirical question that has been addressed by psychological research. In Chapter 3, I describe my experimental research testing the effect of consensus interventions, as well as the psychological insights gleaned from computational cognitive models.

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Quantifying the consensus on anthropogenic global warming in the scientific literature

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Abstract
We analyze the evolution of the scientific consensus on anthropogenic global warming (AGW) in the peer-reviewed scientific literature, examining 11 944 climate abstracts from 1991–2011 matching the topics ‘global climate change’ or ‘global warming’. We find that 66.4% of abstracts expressed no position on AGW, 32.6% endorsed AGW, 0.7% rejected AGW and 0.3% were uncertain about the cause of global warming. Among abstracts expressing a position on AGW, 97.1% endorsed the consensus position that humans are causing global warming. In a second phase of this study, we invited authors to rate their own papers. Compared to abstract ratings, a smaller percentage of self-rated papers expressed no position on AGW (35.5%). Among self-rated papers expressing a position on AGW, 97.2% endorsed the consensus. For both abstract ratings and authors’ self-ratings, the percentage of endorsements among papers expressing a position on AGW marginally increased over time. Our analysis indicates that the number of papers rejecting the consensus on AGW is a vanishingly small proportion of the published research.

Keywords: scientific consensus, anthropogenic global warming, peer-review, global climate change, Intergovernmental Panel on Climate Change

S Online supplementary data available from stacks.iop.org/ERL/8/024024/mmedia

1. Introduction

An accurate perception of the degree of scientific consensus is an essential element to public support for climate policy (Ding *et al* 2011). Communicating the scientific consensus also increases people’s acceptance that climate change (CC) is happening (Lewandowsky *et al* 2012). Despite numerous indicators of a consensus, there is wide public perception that climate scientists disagree over the fundamental cause of global warming (GW; Leiserowitz *et al* 2012, Pew 2012). In the most comprehensive analysis performed to date, we have extended the analysis of peer-reviewed climate papers in Oreskes (2004). We examined a large sample of the scientific

Table 1. Definitions of each type of research category.

Category	Description	Example
(1) Impacts	Effects and impacts of climate change on the environment, ecosystems or humanity	'... global climate change together with increasing direct impacts of human activities, such as fisheries, are affecting the population dynamics of marine top predators'
(2) Methods	Focus on measurements and modeling methods, or basic climate science not included in the other categories	'This paper focuses on automating the task of estimating Polar ice thickness from airborne radar data...'
(3) Mitigation	Research into lowering CO_2 emissions or atmospheric CO_2 levels	'This paper presents a new approach for a nationally appropriate mitigation actions framework that can unlock the huge potential for greenhouse gas mitigation in dispersed energy end-use sectors in developing countries'
(4) Not climate-related	Social science, education, research about people's views on climate	'This paper discusses the use of multimedia techniques and augmented reality tools to bring across the risks of global climate change'
(5) Opinion	Not peer-reviewed articles	'While the world argues about reducing global warming, chemical engineers are getting on with the technology. Charles Butcher has been finding out how to remove carbon dioxide from flue gas'
(6) Paleoclimate	Examining climate during pre-industrial times	'Here, we present a pollen-based quantitative temperature reconstruction from the midlatitudes of Australia that spans the last 135 000 years...'

literature on global CC, published over a 21 year period, in order to determine the level of scientific consensus that human activity is very likely causing most of the current GW (anthropogenic global warming, or AGW).

Surveys of climate scientists have found strong agreement (97–98%) regarding AGW amongst publishing climate experts (Doran and Zimmerman 2009, Anderegg *et al* 2010). Repeated surveys of scientists found that scientific agreement about AGW steadily increased from 1996 to 2009 (Bray 2010). This is reflected in the increasingly definitive statements issued by the Intergovernmental Panel on Climate Change on the attribution of recent GW (Houghton *et al* 1996, 2001, Solomon *et al* 2007).

The peer-reviewed scientific literature provides a ground-level assessment of the degree of consensus among publishing scientists. An analysis of abstracts published from 1993–2003 matching the search 'global climate change' found that none of 928 papers disagreed with the consensus position on AGW (Oreskes 2004). This is consistent with an analysis of citation networks that found a consensus on AGW forming in the early 1990s (Shwed and Bearman 2010).

Despite these independent indicators of a scientific consensus, the perception of the US public is that the scientific community still disagrees over the fundamental cause of GW. From 1997 to 2007, public opinion polls have indicated around 60% of the US public believes there is significant disagreement among scientists about whether GW was happening (Nisbet and Myers 2007). Similarly, 57% of the US public either disagreed or were unaware that scientists agree that the earth is very likely warming due to human activity (Pew 2012).

Through analysis of climate-related papers published from 1991 to 2011, this study provides the most comprehensive analysis of its kind to date in order to quantify and evaluate the level and evolution of consensus over the last two decades.

2. Methodology

This letter was conceived as a 'citizen science' project by volunteers contributing to the Skeptical Science website (www.skepticalscience.com). In March 2012, we searched the ISI Web of Science for papers published from 1991–2011 using topic searches for 'global warming' or 'global climate change'. Article type was restricted to 'article', excluding books, discussions, proceedings papers and other document types. The search was updated in May 2012 with papers added to the Web of Science up to that date.

We classified each abstract according to the type of research (category) and degree of endorsement. Written criteria were provided to raters for category (table 1) and level of endorsement of AGW (table 2). Explicit endorsements were divided into non-quantified (e.g., humans are contributing to global warming without quantifying the contribution) and quantified (e.g., humans are contributing more than 50% of global warming, consistent with the 2007 IPCC statement that most of the global warming since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations).

Abstracts were randomly distributed via a web-based system to raters with only the title and abstract visible. All other information such as author names and affiliations, journal and publishing date were hidden. Each abstract was categorized by two independent, anonymized raters. A team of 12 individuals completed 97.4% (23 061) of the ratings; an

Table 2. Definitions of each level of endorsement of AGW.

Level of endorsement	Description	Example
(1) Explicit endorsement with quantification	Explicitly states that humans are the primary cause of recent global warming	'The global warming during the 20th century is caused mainly by increasing greenhouse gas concentration especially since the late 1980s'
(2) Explicit endorsement without quantification	Explicitly states humans are causing global warming or refers to anthropogenic global warming/climate change as a known fact	'Emissions of a broad range of greenhouse gases of varying lifetimes contribute to global climate change'
(3) Implicit endorsement	Implies humans are causing global warming. E.g., research assumes greenhouse gas emissions cause warming without explicitly stating humans are the cause	'...carbon sequestration in soil is important for mitigating global climate change'
(4a) No position	Does not address or mention the cause of global warming	
(4b) Uncertain	Expresses position that human's role on recent global warming is uncertain/undefined	'While the extent of human-induced global warming is inconclusive...'
(5) Implicit rejection	Implies humans have had a minimal impact on global warming without saying so explicitly E.g., proposing a natural mechanism is the main cause of global warming	'...anywhere from a major portion to all of the warming of the 20th century could plausibly result from natural causes according to these results'
(6) Explicit rejection without quantification	Explicitly minimizes or rejects that humans are causing global warming	'...the global temperature record provides little support for the catastrophic view of the greenhouse effect'
(7) Explicit rejection with quantification	Explicitly states that humans are causing less than half of global warming	'The human contribution to the CO_2 content in the atmosphere and the increase in temperature is negligible in comparison with other sources of carbon dioxide emission'

additional 12 contributed the remaining 2.6% (607). Initially, 27% of category ratings and 33% of endorsement ratings disagreed. Raters were then allowed to compare and justify or update their rating through the web system, while maintaining anonymity. Following this, 11% of category ratings and 16% of endorsement ratings disagreed; these were then resolved by a third party.

Upon completion of the final ratings, a random sample of 1000 'No Position' category abstracts were re-examined to differentiate those that did not express an opinion from those that take the position that the cause of GW is uncertain. An 'Uncertain' abstract explicitly states that the cause of global warming is not yet determined (e.g., '...the extent of human-induced global warming is inconclusive...') while a 'No Position' abstract makes no statement on AGW.

To complement the abstract analysis, email addresses for 8547 authors were collected, typically from the corresponding author and/or first author. For each year, email addresses were obtained for at least 60% of papers. Authors were emailed an invitation to participate in a survey in which they rated their own published papers (the entire content of the article, not just the abstract) with the same criteria as used by the independent rating team. Details of the survey text are provided in the supplementary information (available at stacks.iop.org/ERL/8/024024/mmedia).

3. Results

The ISI search generated 12 465 papers. Eliminating papers that were not peer-reviewed (186), not climate-related (288) or without an abstract (47) reduced the analysis to 11 944 papers written by 29 083 authors and published in 1980 journals. To simplify the analysis, ratings were consolidated into three groups: endorsements (including implicit and explicit; categories 1–3 in table 2), no position (category 4) and rejections (including implicit and explicit; categories 5–7).

We examined four metrics to quantify the level of endorsement:

(1) The percentage of endorsements/rejections/undecideds among all abstracts.
(2) The percentage of endorsements/rejections/undecideds among only those abstracts expressing a position on AGW.
(3) The percentage of scientists authoring endorsement/rejection abstracts among all scientists.
(4) The same percentage among only those scientists who expressed a position on AGW (table 3).

3.1. Endorsement percentages from abstract ratings

Among abstracts that expressed a position on AGW, 97.1% endorsed the scientific consensus. Among scientists who expressed a position on AGW in their abstract, 98.4% endorsed the consensus.

The time series of each level of endorsement of the consensus on AGW was analyzed in terms of the number of abstracts (figure 1(a)) and the percentage of abstracts (figure 1(b)). Over time, the no position

Table 3. Abstract ratings for each level of endorsement, shown as percentage and total number of papers.

Position	% of all abstracts	% among abstracts with AGW position (%)	% of all authors	% among authors with AGW position (%)
Endorse AGW	32.6% (3896)	97.1	34.8% (10 188)	98.4
No AGW position	66.4% (7930)	—	64.6% (18 930)	—
Reject AGW	0.7% (78)	1.9	0.4% (124)	1.2
Uncertain on AGW	0.3% (40)	0.8	0.2% (44)	0.4

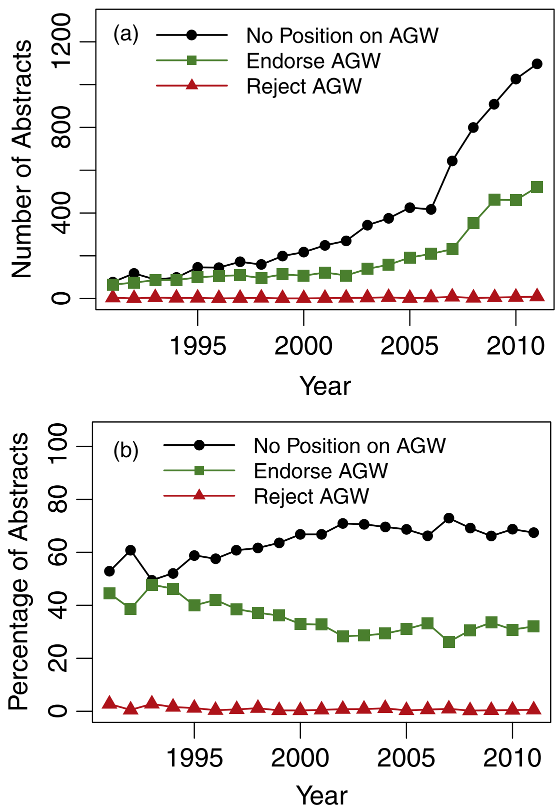

Figure 1. (a) Total number of abstracts categorized into endorsement, rejection and no position. (b) Percentage of endorsement, rejection and no position/undecided abstracts. Uncertain comprise 0.5% of no position abstracts.

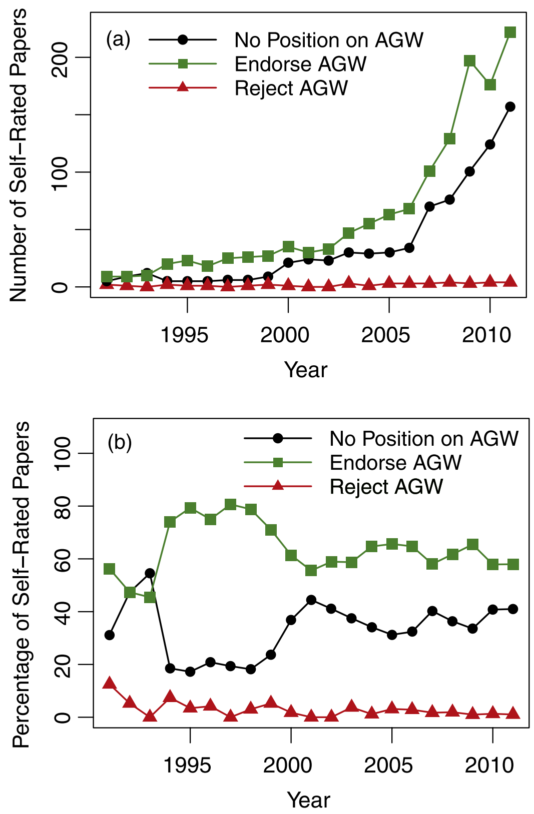

Figure 2. (a) Total number of endorsement, rejection and no position papers as self-rated by authors. Year is the published year of each self-rated paper. (b) Percentage of self-rated endorsement, rejection and no position papers.

percentage has increased (simple linear regression trend $0.87\% \pm 0.28\%\ \mathrm{yr}^{-1}$, 95% CI, $R^2 = 0.66$, $p < 0.001$) and the percentage of papers taking a position on AGW has equally decreased.

The average numbers of authors per endorsement abstract (3.4) and per no position abstract (3.6) are both significantly larger than the average number of authors per rejection abstract (2.0). The scientists originated from 91 countries (identified by email address) with the highest representation from the USA ($N = 2548$) followed by the United Kingdom ($N = 546$), Germany ($N = 404$) and Japan ($N = 379$) (see supplementary table S1 for full list, available at stacks.iop.org/ERL/8/024024/mmedia).

3.2. Endorsement percentages from self-ratings

We emailed 8547 authors an invitation to rate their own papers and received 1200 responses (a 14% response rate). After excluding papers that were not peer-reviewed, not climate-related or had no abstract, 2142 papers received self-ratings from 1189 authors. The self-rated levels of endorsement are shown in table 4. Among self-rated papers that stated a position on AGW, 97.2% endorsed the consensus. Among self-rated papers not expressing a position on AGW in the abstract, 53.8% were self-rated as endorsing the consensus. Among respondents who authored a paper expressing a view on AGW, 96.4% endorsed the consensus.

Table 4. Self-ratings for each level of endorsement, shown as percentage and total number of papers.

Position	% of all papers	% among papers with AGW position (%)	% of respondents	% among respondents with AGW position (%)
Endorse AGW[a]	62.7% (1342)	97.2	62.7% (746)	96.4
No AGW position[b]	35.5% (761)	—	34.9% (415)	—
Reject AGW[c]	1.8% (39)	2.8	2.4% (28)	3.6

[a] Self-rated papers that endorse AGW have an average endorsement rating less than 4 (1 = explicit endorsement with quantification, 7 = explicit rejection with quantification).

[b] Undecided self-rated papers have an average rating equal to 4.

[c] Rejection self-rated papers have an average rating greater than 4.

Table 5. Comparison of our abstract rating to self-rating for papers that received self-ratings.

Position	Abstract rating	Self-rating
Endorse AGW	791 (36.9%)	1342 (62.7%)
No AGW position or undecided	1339 (62.5%)	761 (35.5%)
Reject AGW	12 (0.6%)	39 (1.8%)

Figure 2(a) shows the level of self-rated endorsement in terms of number of abstracts (the corollary to figure 1(a)) and figure 2(b) shows the percentage of abstracts (the corollary to figure 1(b)). The percentage of self-rated rejection papers decreased (simple linear regression trend $-0.25\% \pm 0.18\%$ yr^{-1}, 95% CI, $R^2 = 0.28, p = 0.01$, figure 2(b)). The time series of self-rated no position and consensus endorsement papers both show no clear trend over time.

A direct comparison of abstract rating versus self-rating endorsement levels for the 2142 papers that received a self-rating is shown in table 5. More than half of the abstracts that we rated as 'No Position' or 'Undecided' were rated 'Endorse AGW' by the paper's authors.

Figure 3 compares the percentage of papers endorsing the scientific consensus among all papers that express a position endorsing or rejecting the consensus. The year-to-year variability is larger in the self-ratings than in the abstract ratings due to the smaller sample sizes in the early 1990s. The percentage of AGW endorsements for both self-rating and abstract-rated papers increase marginally over time (simple linear regression trends $0.10 \pm 0.09\%$ yr^{-1}, 95% CI, $R^2 = 0.20, p = 0.04$ for abstracts, $0.35 \pm 0.26\%$ yr^{-1}, 95% CI, $R^2 = 0.26, p = 0.02$ for self-ratings), with both series approaching approximately 98% endorsements in 2011.

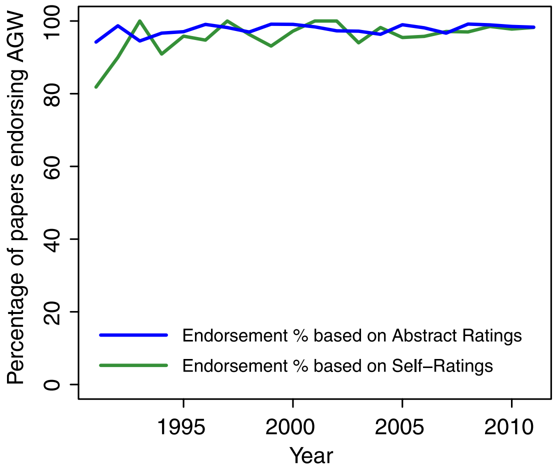

Figure 3. Percentage of papers endorsing the consensus among only papers that express a position endorsing or rejecting the consensus.

4. Discussion

Of note is the large proportion of abstracts that state no position on AGW. This result is expected in consensus situations where scientists '*... generally focus their discussions on questions that are still disputed or unanswered rather than on matters about which everyone agrees*' (Oreskes 2007, p 72). This explanation is also consistent with a description of consensus as a 'spiral trajectory' in which '*initially intense contestation generates rapid settlement and induces a spiral of new questions*' (Shwed and Bearman 2010); the fundamental science of AGW is no longer controversial among the publishing science community and the remaining debate in the field has moved to other topics. This is supported by the fact that more than half of the self-rated endorsement papers did not express a position on AGW in their abstracts.

The self-ratings by the papers' authors provide insight into the nature of the scientific consensus amongst publishing scientists. For both self-ratings and our abstract ratings, the percentage of endorsements among papers expressing a position on AGW marginally increased over time, consistent with Bray (2010) in finding a strengthening consensus.

4.1. Sources of uncertainty

The process of determining the level of consensus in the peer-reviewed literature contains several sources of uncertainty, including the representativeness of the sample, lack of clarity in the abstracts and subjectivity in rating the abstracts.

We address the issue of representativeness by selecting the largest sample to date for this type of literature analysis. Nevertheless, 11 944 papers is only a fraction of the climate literature. A Web of Science search for 'climate change' over the same period yields 43 548 papers, while a search for 'climate' yields 128 440 papers. The crowd-sourcing techniques employed in this analysis could be expanded to include more papers. This could facilitate an approach approximating the methods of Doran and Zimmerman (2009), which measured the level of scientific consensus for varying degrees of expertise in climate science. A similar approach could analyze the level of consensus among climate papers depending on their relevance to the attribution of GW.

Another potential area of uncertainty involved the text of the abstracts themselves. In some cases, ambiguous language made it difficult to ascertain the intended meaning of the authors. Naturally, a short abstract could not be expected to communicate all the details of the full paper. The implementation of the author self-rating process allowed us to look beyond the abstract. A comparison between self-ratings and abstract ratings revealed that categorization based on the abstract alone underestimates the percentage of papers taking a position on AGW.

Lastly, some subjectivity is inherent in the abstract rating process. While criteria for determining ratings were defined prior to the rating period, some clarifications and amendments were required as specific situations presented themselves. Two sources of rating bias can be cited: first, given that the raters themselves endorsed the scientific consensus on AGW, they may have been more likely to classify papers as sharing that endorsement. Second, scientific reticence (Hansen 2007) or 'erring on the side of least drama' (ESLD; Brysse *et al* 2012) may have exerted an opposite effect by biasing raters towards a 'no position' classification. These sources of bias were partially addressed by the use of multiple independent raters and by comparing abstract rating results to author self-ratings. A comparison of author ratings of the full papers and abstract ratings reveals a bias toward under-counting of endorsement papers in the abstract ratings (mean difference 0.6 in units of endorsement level). This mitigated concerns about rater subjectivity, but suggests that scientific reticence and ESLD remain possible biases in the abstract ratings process. The potential impact of initial rating disagreements was also calculated and found to have minimal impact on the level of consensus (see supplemental information, section S1 available at stacks.iop.org/ERL/8/024024/mmedia).

4.2. Comparisons with previous studies

Our sample encompasses those surveyed by Oreskes (2004) and Schulte (2008) and we can therefore directly compare the results. Oreskes (2004) analyzed 928 papers from 1993 to 2003. Over the same period, we found 932 papers matching the search phrase 'global climate change' (papers continue to be added to the ISI database). From that subset we eliminated 38 papers that were not peer-reviewed, climate-related or had no abstract. Of the remaining 894, none rejected the consensus, consistent with Oreskes' result. Oreskes determined that 75% of papers endorsed the consensus, based on the assumption that mitigation and impact papers implicitly endorse the consensus. By comparison, we found that 28% of the 894 abstracts endorsed AGW while 72% expressed no position. Among the 71 papers that received self-ratings from authors, 69% endorse AGW, comparable to Oreskes' estimate of 75% endorsements.

An analysis of 539 'global climate change' abstracts from the Web of Science database over January 2004 to mid-February 2007 found 45% endorsement and 6% rejection (Schulte 2008). Our analysis over a similar period (including all of February 2007) produced 529 papers—the reason for this discrepancy is unclear as Schulte's exact methodology is not provided. Schulte estimated a higher percentage of endorsements and rejections, possibly because the strict methodology we adopted led to a greater number of 'No Position' abstracts. Schulte also found a significantly greater number of rejection papers, including 6 explicit rejections compared to our 0 explicit rejections. See the supplementary information (available at stacks.iop.org/ERL/8/024024/mmedia) for a tabulated comparison of results. Among 58 self-rated papers, only one (1.7%) rejected AGW in this sample. Over the period of January 2004 to February 2007, among 'global climate change' papers that state a position on AGW, we found 97% endorsements.

5. Conclusion

The public perception of a scientific consensus on AGW is a necessary element in public support for climate policy (Ding *et al* 2011). However, there is a significant gap between public perception and reality, with 57% of the US public either disagreeing or unaware that scientists overwhelmingly agree that the earth is warming due to human activity (Pew 2012).

Contributing to this 'consensus gap' are campaigns designed to confuse the public about the level of agreement among climate scientists. In 1991, Western Fuels Association conducted a \$510 000 campaign whose primary goal was to '*reposition global warming as theory (not fact)*'. A key strategy involved constructing the impression of active scientific debate using dissenting scientists as spokesmen (Oreskes 2010). The situation is exacerbated by media treatment of the climate issue, where the normative practice of providing opposing sides with equal attention has allowed a vocal minority to have their views amplified (Boykoff and Boykoff 2004). While there are indications that the situation has improved in the UK and USA prestige press (Boykoff 2007), the UK tabloid press showed no indication of improvement from 2000 to 2006 (Boykoff and Mansfield 2008).

The narrative presented by some dissenters is that the scientific consensus is '*... on the point of collapse*' (Oddie 2012) while '*... the number of scientific "heretics" is growing with each passing year*' (Allègre *et al* 2012). A systematic, comprehensive review of the literature provides quantitative evidence countering this assertion. The number of papers rejecting AGW is a miniscule proportion of the published research, with the percentage slightly decreasing over time. Among papers expressing a position on AGW, an overwhelming percentage (97.2% based on self-ratings, 97.1% based on abstract ratings) endorses the scientific consensus on AGW.

Acknowledgments

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REPLY

Consensus on consensus: a synthesis of consensus estimates on human-caused global warming

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Keywords: scientific consensus, climate change, anthropogenic global warming

Supplementary material for this article is available online

Abstract

The consensus that humans are causing recent global warming is shared by 90%–100% of publishing climate scientists according to six independent studies by co-authors of this paper. Those results are consistent with the 97% consensus reported by Cook *et al* (*Environ. Res. Lett.* **8** 024024) based on 11 944 abstracts of research papers, of which 4014 took a position on the cause of recent global warming. A survey of authors of those papers ($N = 2412$ papers) also supported a 97% consensus. Tol (2016 *Environ. Res. Lett.* **11** 048001) comes to a different conclusion using results from surveys of non-experts such as economic geologists and a self-selected group of those who reject the consensus. We demonstrate that this outcome is not unexpected because the level of consensus correlates with expertise in climate science. At one point, Tol also reduces the apparent consensus by assuming that abstracts that do not explicitly state the cause of global warming ('no position') represent non-endorsement, an approach that if applied elsewhere would reject consensus on well-established theories such as plate tectonics. We examine the available studies and conclude that the finding of 97% consensus in published climate research is robust and consistent with other surveys of climate scientists and peer-reviewed studies.

1. Introduction

Climate scientists overwhelmingly agree that humans are causing recent global warming. The consensus position is articulated by the Intergovernmental Panel on Climate Change (IPCC) statement that 'human influence has been the dominant cause of the observed warming since the mid-20th century' (Qin *et al* 2014, p 17). The National Academies of Science from 80 countries have issued statements endorsing the consensus position (table S2). Nevertheless, the existence of the consensus continues to be questioned. Here we summarize studies that quantify expert views and examine common flaws in criticisms of consensus estimates. In particular, we are responding to a comment by Tol (2016) on Cook *et al* (2013, referred to as C13). We show that contrary to Tol's claim that the results of C13 differ from earlier studies, the consensus of experts is robust across all the studies conducted by coauthors of this correspondence.

Tol's erroneous conclusions stem from conflating the opinions of non-experts with experts and assuming that lack of affirmation equals dissent. A detailed technical response to Tol is provided in (S1) where we specifically address quibbles about abstract ID numbers, timing of ratings, inter-rater communication and agreement, and access to ratings. None of those points raised by Tol affect the calculated consensus. Most importantly, the 97% consensus derived from abstract ratings is validated by the authors of the papers studied who responded to our survey ($N = 2142$ papers) and also reported a 97% consensus in papers taking a position. The remainder of this paper shows that a high level of scientific consensus, in agreement with our results, is a robust finding in the scientific literature. This is used to illustrate and address the issues raised by Tol that are relevant to our main conclusion.

2. Assessing expert consensus

Efforts to measure scientific consensus need to identify a relevant and representative population of experts, assess their professional opinion in an appropriate manner, and avoid distortions from ambiguous elements in the sample. Approaches that have been employed to assess expert views on anthropogenic global warming (AGW) include analysing peer-reviewed climate papers (Oreskes 2004; C13), surveying members of the relevant scientific community (Bray and von Storch 2007, Doran and Zimmerman 2009, Bray 2010, Rosenberg *et al* 2010, Farnsworth and Lichter 2012, Verheggen *et al* 2014, Stenhouse *et al* 2014, Carlton *et al* 2015), compiling public statements by scientists (Anderegg *et al* 2010), and mathematical analyses of citation patterns (Shwed and Bearman 2010). We define domain experts as scientists who have published peer-reviewed research in that domain, in this case, climate science. Consensus estimates for these experts are listed in table 1, with the range of estimates resulting primarily from differences in selection of the expert pool, the definition of what entails the consensus position, and differences in treatment of no position responses/papers.

The studies in table 1 have taken various approaches to selecting and querying pools of experts. Oreskes (2004) identified expressions of views on AGW in the form of peer-reviewed papers on 'global climate change'. This analysis found no papers rejecting AGW in a sample of 928 papers published from 1993 to 2003, that is, 100% consensus among papers stating a position on AGW.

Following a similar methodology, C13 analysed the abstracts of 11 944 peer-reviewed papers published between 1991 and 2011 that matched the search terms 'global climate change' or 'global warming' in the ISI Web of Science search engine. Among the 4014 abstracts stating a position on human-caused global warming, 97.1% were judged as having implicitly or explicitly endorsed the consensus. In addition, the study authors were invited to rate their own papers, based on the contents of the full paper, not just the abstract. Amongst 1381 papers self-rated by their authors as stating a position on human-caused global warming, 97.2% endorsed the consensus.

Shwed and Bearman (2010) employed citation analysis of 9432 papers on global warming and climate published from 1975 to 2008. Unlike surveys or classifications of abstracts, this method was entirely mathematical and blind to the content of the literature being examined. By determining the modularity of citation networks, they concluded, 'Our results reject the claim of inconclusive science on climate change and identify the emergence of consensus earlier than previously thought' (p. 831). Although this method does not produce a numerical consensus value, it independently demonstrates the same level of scientific consensus on AGW as exists for the fact that smoking causes cancer.

Anderegg *et al* (2010) identified climate experts as those who had authored at least 20 climate-related publications and chose their sample from those who had signed public statements regarding climate change. By combining published scientific papers and public statements, Anderegg *et al* determined that 97%–98% of the 200 most-published climate scientists endorsed the IPCC conclusions on AGW.

Other studies have directly queried scientists, typically choosing a sample of scientists and identifying subsamples of those who self-identify as climate scientists or actively publish in the field. Doran and Zimmerman (2009) surveyed 3146 Earth scientists, asking whether 'human activity is a significant contributing factor in changing mean global temperatures,' and subsampled those who were actively publishing climate scientists. Overall, they found that 82% of Earth scientists indicated agreement, while among the subset with greatest expertise in climate science, the agreement was 97.4%.

Bray and von Storch (2007) and Bray (2010) repeatedly surveyed different populations of climate scientists in 1996, 2003 and 2008. The questions did not specify a time period for climate change (indeed, in 2008, 36% of the participants defined the term 'climate change' to refer to 'changes in climate at any time for whatever reason'). Therefore, the reported consensus estimates of 40% (1996) and 53% (2003) (which included participants not stating a view on AGW) suffered from both poor control of expert

Table 1. Estimates of consensus on human-caused global warming among climate experts.

		Total sample (including non-publishing climatologists)			Sub-sample of publishing climatologists			
Source	Year(s)	Consensus	*N*	Description	Consensus	*N*	Description	Definition of consensus
Gallup (1991)	1991	66%	400	AMS/AGU members	67%	97	Currently Performing Research in Area Global Warming	In your opinion, is human-induced greenhouse warming now occurring?
Oreskes (2004)	1993–2003				100%	928	Peer-reviewed papers on 'global climate change'	'[M]ost of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations'
Bray and von Storch (2007)	1996	40%	539	1997: 5 countries (US, Canada, Germany, Denmark, Italy)				Climate change is mostly the result of anthropogenic causes
Bray and von Storch (2007)	2003	53%	530	2003: 30 countries				Climate change is mostly the result of anthropogenic causes
Doran and Zimmerman (2009)	2009	82%	3146	Earth scientists	97%	77	Climatologists who are active publishers of climate research	Human activity is a significant contributing factor in changing mean global temperatures
Anderegg *et al* (2010)	2010	66%	1372	Signatories of public statements about climate change	97%	200	Top 200 most published authors (of climate-related papers)	Anthropogenic greenhouse gases have been responsible for 'most' of the 'unequivocal' warming of the Earth's average global temperature over the second half of the 20th century
Bray (2010)	2008				83.5%	370	Authors of climate journals, authors from Oreskes' (2004) sample, scientists from relevant institutes (NCAR, AMS, etc)	How convinced are you that most of recent or near future climate change is, or will be, a result of anthropogenic causes?
Rosenberg *et al* (2010)	2005				88.5%	433	US climate scientists authoring articles in scientific journals that highlight climate change research	Scientists can say with great certainty that human activities are accelerating global warming
Farnsworth and Lichter (2012)	2007	84%	489	AMS/AGU members				In your opinion, is human-induced greenhouse warming now occurring?
Cook *et al* (2013)	1991–2011				97.1% 97.2%	4014 abstracts 1381 self-rated papers	Published peer-reviewed papers on 'global climate change' or 'global warming' that state a position on AGW	1. Explicitly states that humans are the primary cause of recent global warming 2. Explicitly states humans are causing global warming 3. Implies humans are causing global warming.

Table 1. (Continued.)

Source	Year(s)	Total sample (including non-publishing climatologists)			Sub-sample of publishing climatologists			Definition of consensus
		Consensus	N	Description	Consensus	N	Description	
								4a. Does not address or mention the cause of global warming 4b. Expresses position that human's role on recent global warming is uncertain/undefined 5. Implies humans have had a minimal impact on global warming without saying so explicitly 6. Explicitly minimizes or rejects that humans are causing global warming 7. Explicitly states that humans are causing less than half of global warming
Stenhouse et al (2014)	2013	73%	1821	AMS members	93%	124	Self-reported expertise is climate science, publication focus is mostly climate	Humans are a contributing cause of global warming over the past 150 years
Verheggen et al (2014)	2012	84%	1461 (Q1)		89% (Q1)	623 (Q1)	Published more than 10 climate-related papers (self-reported)	Q1. Over half of global warming since the mid-20th century can be attributed to human-induced increases in atmospheric GHG concentrations
		86%	1682 (Q3)		91% (Q3)	729 (Q3)		Q3. Greenhouse gases have made the strongest or tied-strongest contribution (out of different factors considered) to the reported global warming of ~0.8 °C since pre-industrial times
Pew Research Center (2015)	2015	87%	3748	AAAS members	93%	132	Working PhD Earth scientist	Climate change is mostly due to human activity
Carlton et al (2015)	2014	91.9%	698	Survey of biophysical scientists across disciplines at universities in the Big 10 Conference	96.7%	306	Those who indicated that 'The majority of my research concerns climate change or the impacts of climate change.'	Response to the following: (1) When compared with pre-1800's levels, do you think that mean global temperatures have generally risen, fallen, or remained relatively constant, and (2) Do you think human activity is a significant contributing factor in changing mean global temperatures?

selection and ambiguous questions. Their 2008 study, finding 83% agreement, had a more robust sample selection and a more specific definition of the consensus position on attribution.

Verheggen *et al* (2014) surveyed 1868 scientists, drawn in part from a public repository of climate scientists (the same source as was used by Anderegg *et al*), and from scientists listed in C13, supplemented by authors of recent climate-related articles and with particular effort expended to include signatories of public statements critical of mainstream climate science. 85% of all respondents (which included a likely overrepresentation of contrarian non-scientists) who stated a position agreed that anthropogenic greenhouse gases (GHGs) are the dominant driver of recent global warming. Among respondents who reported having authored more than 10 peer-reviewed climate-related publications, approximately 90% agreed that greenhouse gas emissions are the primary cause of global warming.

Stenhouse *et al* (2014) collected responses from 1854 members of the American Meteorological Society (AMS). Among members whose area of expertise was climate science, with a publication focus on climate, 78% agreed that the cause of global warming over the past 150 years was mostly human, with an additional 10% (for a total of 88%) indicating the warming was caused equally by human activities and natural causes. An additional 6% answered 'I do not believe we know enough to determine the degree of human causation.' To make a more precise comparison with the Doran and Zimmerman findings, these respondents were emailed one additional survey question to ascertain if they thought human activity had contributed to the global warming that has occurred over the past 150 years; among the 6% who received this question, 5% indicated there had been some human contribution to the warming. Thus, Stenhouse *et al* (2014) concluded that '93% of actively publishing climate scientists indicated they are convinced that humans have contributed to global warming.'

Carlton *et al* (2015) adapted questions from Doran and Zimmerman (2009) to survey 698 biophysical scientists across various disciplines, finding that 91.9% of them agreed that (1) mean global temperatures have generally risen compared with pre-1800s levels and that (2) human activity is a significant contributing factor in changing mean global temperatures. Among the 306 who indicated that 'the majority of my research concerns climate change or the impacts of climate change', there was 96.7% consensus on the existence of AGW.

The Pew Research Center (2015) conducted a detailed survey of 3748 members of the American Association for the Advancement of Science (AAAS) to assess views on several key science topics. Across this group, 87% agreed that 'Earth is warming due mostly to human activity.' Among a subset of working PhD Earth scientists, 93% agreed with this statement.

Despite the diversity of sampling techniques and approaches, a consistent picture of an overwhelming consensus among experts on anthropogenic climate change has emerged from these studies. Another recurring finding is that higher scientific agreement is associated with higher levels of expertise in climate science (Oreskes 2004, Doran and Zimmerman 2009, Anderegg 2010, Verheggen *et al* 2014).

3. Interpreting consensus data

How can vastly different interpretations of consensus arise? A significant contributor to variation in consensus estimates is the conflation of *general* scientific opinion with *expert* scientific opinion. Figure 1 demonstrates that consensus estimates are highly sensitive to the expertise of the sampled group. An accurate estimate of scientific consensus reflects the level of agreement among experts in climate science; that is, scientists publishing peer-reviewed research on climate change. As shown in table 1, low estimates of consensus arise from samples that include non-experts such as scientists (or non-scientists) who are not actively publishing climate research, while samples of experts are consistent in showing overwhelming consensus.

Tol (2016) reports consensus estimates ranging from 7% to 100% from the same studies described above. His broad range is due to sub-groupings of scientists with different levels of expertise. For example, the sub-sample with 7% agreement was selected from those expressing an 'unconvinced' position on AGW (Verheggen *et al* 2014). This selection criterion does not provide a valid estimate of consensus for two reasons: first, this subsample was selected based on opinion on climate change, predetermining the level of estimated consensus. Second, this does not constitute a sample of experts, as non-experts were included. Anderegg (2010) found that nearly one-third of the unconvinced group lacked a PhD, and only a tiny fraction had a PhD in a climate-relevant discipline. Eliminating less published scientists from both these samples resulted in consensus values of 90% and 97%–98% for Verheggen *et al* (2014) and Anderegg *et al* (2010), respectively. Tol's (2016) conflation of unrepresentative non-expert sub-samples and samples of climate experts is a misrepresentation of the results of previous studies, including those published by a number of coauthors of this paper.

In addition to varying with expertise, consensus estimates may differ based on their approach to studies or survey responses that do not state an explicit position on AGW. Taking a conservative approach, C13 omitted abstracts that did not state a position on AGW to derive its consensus estimate of 97%; a value shown to be robust when compared with the estimate derived from author responses. In contrast, in one analysis,

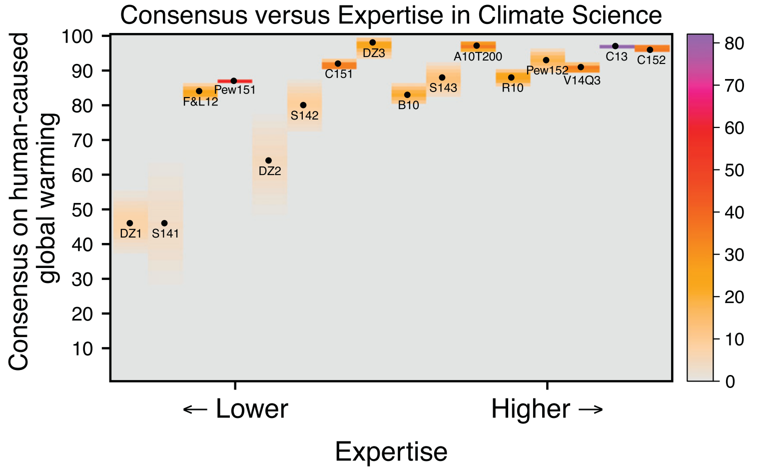

Figure 1. Level of consensus on AGW versus expertise across different studies. Right colour bar indicates posterior density of Bayesian 99% credible intervals. Only consensus estimates obtained over the last 10 years are included (see S2 for further details and tabulation of acronyms).

Tol (2016) effectively treats no-position abstracts as rejecting AGW, thereby deriving consensus values less than 35%. Equating no-position papers with rejection or an uncertain position on AGW is inconsistent with the expectation of decreasing reference to a consensual position as that consensus strengthens (Oreskes 2007, Shwed and Bearman 2010). Powell (2015) shows that applying Tol's method to the established paradigm of plate tectonics would lead Tol to reject the scientific consensus in that field because nearly all current papers would be classified as taking 'no position'.

4. Conclusion

We have shown that the scientific consensus on AGW is robust, with a range of 90%–100% depending on the exact question, timing and sampling methodology. This is supported by multiple independent studies despite variations in the study timing, definition of consensus, or differences in methodology including surveys of scientists, analyses of literature or of citation networks. Tol (2016) obtains lower consensus estimates through a flawed methodology, for example by conflating non-expert and expert views, and/or making unsupported assumptions about sources that do not specifically state a position about the consensus view.

An accurate understanding of scientific consensus, and the ability to recognize attempts to undermine it, are important for public climate literacy. Public perception of the scientific consensus has been found to be a gateway belief, affecting other climate beliefs and attitudes including policy support (Ding *et al* 2011, McCright *et al* 2013, van der Linden *et al* 2015). However, many in the public, particularly in the US, still believe scientists disagree to a large extent about AGW (Leiserowitz *et al* 2015), and many political leaders, again particularly in the US, insist that this is so. Leiserowitz *et al* (2015) found that only 12% of the US public accurately estimate the consensus at 91%–100%. Further, Plutzer *et al* 2016 found that only 30% of middle-school and 45% of high-school science teachers were aware that the scientific consensus is above 80%, with 31% of teachers who teach climate change presenting contradictory messages that emphasize both the consensus and the minority position.

Misinformation about climate change has been observed to reduce climate literacy levels (McCright *et al* 2016, Ranney and Clark 2016), and manufacturing doubt about the scientific consensus on climate change is one of the most effective means of reducing acceptance of climate change and support for mitigation policies (Oreskes 2010, van der Linden *et al* 2016). Therefore, it should come as no surprise that the most common argument used in contrarian op-eds about climate change from 2007 to 2010 was that there is no scientific consensus on human-caused global warming (Elsasser and Dunlap 2012, Oreskes and Conway 2011). The generation of climate misinformation persists, with arguments against climate science increasing relative to policy arguments in publications by conservative organisations (Boussalis and Coan 2016).

Consequently, it is important that scientists communicate the overwhelming expert consensus on AGW to the public (Maibach *et al* 2014, Cook and Jacobs 2014). Explaining the 97% consensus has been observed to increase acceptance of climate change (Lewandowsky *et al* 2013, Cook and Lewandowsky 2016) with the greatest change among conservatives (Kotcher *et al* 2014).

From a broader perspective, it doesn't matter if the consensus number is 90% or 100%. The level of scientific agreement on AGW is overwhelmingly high because the supporting evidence is overwhelmingly strong.

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Chapter 3
Modeling climate change belief polarization using Bayesian networks

This chapter is presented in the format of a journal article manuscript.

Cook, J. & Lewandowsky, S. (2016). Rational Irrationality: Modeling climate change belief polarization using Bayesian networks. *Topics in Cognitive Science*. *8*(1), 160-179.

Foreword

As presented in Chapter 2, Cook et al. (2013) and Cook et al. (2016) found an overwhelming scientific consensus on AGW, consistent across a number of independent studies. In contrast, there is a significant gap between the overwhelming scientific agreement and public perception of consensus (Leiserowitz et al., 2015). Addressing this “consensus gap” is the unifying theme of this thesis. However, correcting misperceptions is a complicated affair, with a variety of cognitive processes at play when recipients of corrective information are required to update their beliefs (Lewandowsky, Ecker, Seifert, Schwarz, & Cook, 2012). In order to effectively design interventions that communicate the scientific consensus, one requires an understanding of the psychological processes at play in response to consensus information.

Computational cognitive modelling provides the opportunity to glean insights into the psychological processes that occur when receiving messages about the scientific consensus. Computational cognitive models define psychological processes using computer algorithms, enabling them to run simulations and output quantitative data. By fitting the models to observed data, this potentially offers psychological insights into how the mind works at a deeper level than strict observation.

Developing a cognitive model to simulate belief updating regarding climate change is challenging, particularly given the potential for climate messages to cause contrary responses (Feinberg & Willer, 2011; Hart & Nisbet, 2012; Myers et al., 2012). A number of studies have found that presenting climate information can lower support for climate policies or acceptance of climate change among participants with politically conservative values, such as support for free, unregulated markets.

Despite the complex psychological landscape as it pertains to the issue of climate change, recent research has uncovered one approach to simulating contrary updating using Bayesian Networks (Jern, Chang, & Kemp, 2014). Also known as Bayes Nets, these are graphical networks of causally linked variables where each node in the network represents the degree of belief in that variable. For example, the Bayes Net adopted by Cook and Lewandowsky (2016) included nodes representing AGW (belief in anthropogenic global warming), trust in climate scientists, worldview (for example, the degree of support for free, unregulated markets) and scientific consensus (belief that climate scientists agree on AGW); for details, see the paper itself.

The following paper outlines the experiments I ran involving consensus messaging and the subsequent fitting of my computational cognitive model to the observed data. A key result from the experiment was that U.S. participants with strong free-market support responded to consensus messaging by *reducing* their acceptance of AGW. In other words, they showed contrary updating, otherwise known as the Worldview Backfire Effect (Cook & Lewandowsky, 2011). The opposite effect was found among less extreme free-market supporters in the U.S., and across the entire spectrum of free-market views in Australia.

The computational model found that the driving factor behind the selective contrary updating was an active distrust of climate scientists. This result provoked the question – could a similar contrary response be achieved but in the opposite direction? In other words, might it be possible to cause *misinformation* to backfire, causing an ironic increase in belief in AGW? Chapter 4 will outline how this question was explored experimentally.

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Rational Irrationality: Modeling Climate Change Belief Polarization Using Bayesian Networks

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Abstract

Belief polarization is said to occur when two people respond to the same evidence by updating their beliefs in opposite directions. This response is considered to be "irrational" because it involves contrary updating, a form of belief updating that appears to violate normatively optimal responding, as for example dictated by Bayes' theorem. In light of much evidence that people are capable of normatively optimal behavior, belief polarization presents a puzzling exception. We show that Bayesian networks, or Bayes nets, can simulate rational belief updating. When fit to experimental data, Bayes nets can help identify the factors that contribute to polarization. We present a study into belief updating concerning the reality of climate change in response to information about the scientific consensus on anthropogenic global warming (AGW). The study used representative samples of Australian and U.S. participants. Among Australians, consensus information partially neutralized the influence of worldview, with free-market supporters showing a greater increase in acceptance of human-caused global warming relative to free-market opponents. In contrast, while consensus information overall had a positive effect on perceived consensus among U.S. participants, there was a reduction in perceived consensus and acceptance of human-caused global warming for strong supporters of unregulated free markets. Fitting a Bayes net model to the data indicated that under a Bayesian framework, free-market support is a significant driver of beliefs about climate change and trust in climate scientists. Further, active distrust of climate scientists among a small number of U.S. conservatives drives contrary updating in response to consensus information among this particular group.

Keywords: Belief polarization; Bayes' theorem; Bayesian updating; Climate change

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1. Introduction

Imagine two people with differing beliefs about a publicly contentious issue, such as climate change. One person accepts human-caused global warming, while the other is dismissive of the human role in climate change. How might the two react if told that there is a strong scientific consensus—involving over 95% of all domain experts (Anderegg, Prall, Harold, & Schneider, 2010; Doran & Zimmerman, 2009) and peer-reviewed climate research (Cook et al., 2013; Oreskes, 2004)—regarding human-caused global warming? The person who accepts the presence of a consensus might be expected to strengthen his or her beliefs. However, how will the same information be processed by the "dismissive?" One possibility is that the "dismissive," already distrustful of climate scientists, views the consensus as confirmation of a conspiracy or "groupthink" among scientists, rather than as a reflection of the strength of the scientific evidence. They may, thus, emerge more unconvinced when informed about the scientific consensus. While both parties received the same evidence, their beliefs changed in opposite directions.

This phenomenon is known as belief polarization, and it occurs when people receiving the same information update their beliefs in diverging directions. While belief polarization may occur relatively infrequently (Kuhn & Lao, 1996), it has been observed across a range of contentious issues. In a classic study, supporters and opponents of the death penalty became more set in their views in response to mixed information that both supported and rejected the death penalty (Lord, Ross, & Lepper, 1979). Likewise, in response to a report describing a nuclear breakdown, supporters of nuclear power focused on the fact that the safeguards worked, whereas opponents focused on the breakdown (Plous, 1991). When religious believers and nonbelievers were exposed to a fictitious report disproving the Biblical account of the Resurrection, the religious believers increased their faith, whereas nonbelievers accepted the report and became more skeptical (Batson, 1975). Similarly, news stories about health impacts from climate change have been shown to have polarizing impact across party lines. Information about health impacts "backfire" among Republicans, who showed lower identification with potential victims, whereas Democrats showed greater identification with victims and increased concern about climate impacts in response to the same information (Hart & Nisbet, 2011).

Belief polarization can also be observed in response to evidence supporting a single point of view. When people receive evidence that contradicts their prior basic beliefs, it can result in strengthening of beliefs contrary to the evidence. This is known as contrary updating or the "worldview backfire effect" (Lewandowsky, Ecker, Seifert, Schwarz, & Cook, 2012). To illustrate, Nyhan and Reifler (2010) showed participants mock newspaper articles that suggested that weapons of mass destruction (WMDs) had been found in Iraq after the 2003 invasion, before issuing a correction that WMDs had not been found. This correction induced belief polarization: Conservatives became more likely to believe that Iraq had WMDs, whereas the reverse was observed with liberals.

This type of belief polarization in response to unambiguous evidence is commonly considered an "irrational" response; that is, a deviation from Bayesian belief updating, which is considered to be the normative, optimal way in which a person should change his or her beliefs in light of new evidence (Gerber & Green, 1999). A Bayesian rational agent is thought to update prior beliefs on the basis of new evidence to form a revised "posterior" set of beliefs. Beliefs can only be updated in the direction suggested by the evidence—hence, at first glance, a rational agent could not show an increased belief in a hypothesis (e.g., that there were WMDs in Iraq) when being presented with contrary evidence (i.e., that no WMDs were found).

We argue in this article that although a simple Bayesian view cannot accommodate belief polarization, a more sophisticated variant involving Bayesian belief networks can give rise to polarization even though agents behave entirely "rationally" (Jern, Chang, & Kemp, 2014). We begin by formalizing Bayesian belief updating before introducing Bayesian networks.

Bayes' theorem describes how a rational agent updates its prior belief in a hypothesis H, $P(H)$, in response to new evidence E. The updated or posterior degree of belief in a hypothesis H is expressed as probability $P(H|E)$. Bayes' theorem stipulates that the updated belief is a function of people's prior belief $P(H)$ and the conditional probability $P(E|H)$ of observing the evidence E given H is true.

$$P(H|E) = \frac{P(H) * P(E|H)}{P(E)} \tag{1}$$

According to Bayesian expectations, two people with differing prior beliefs should update their beliefs in the same direction when presented with the same information (Bartels, 2002).

Belief polarization presents a conundrum in light of the large body of evidence that people update their beliefs in accordance with the rules of Bayesian inference. Examples of Bayesian inference include sensorimotor skills (e.g., estimating the velocity of an approaching tennis ball; Körding & Wolpert, 2004), category learning (Sanborn, Griffiths, & Navarro, 2010), and predicting final quantities, such as box office grosses, lifespan, and duration of a Pharaoh's reign from a current value (Griffiths & Tenenbaum, 2006). For example, in an iterative experiment where participants repeatedly estimated lifespans from a person's age, the distribution of estimated values was consistent with the prior distribution of lifespans, indicating Bayesian reasoning among individuals (Lewandowsky, Griffiths, & Kalish, 2009). Conversely, there is also evidence that in some contexts, people make predictions in a non-Bayesian manner, placing undue weight on prior beliefs (Kahneman & Tversky, 1973).

It is, therefore, not surprising that a number of studies have attempted to explain belief polarization under a Bayesian framework (Bullock, 2009). Past studies have employed constrained forms of Bayesian updating, whereby the principal tenets of Bayes' theorems were augmented by non-Bayesian processes (Andreoni & Mylovanov, 2012; Dixit & Weibull, 2007; Gerber & Green, 1999; Wilkins, 2011; Zimper & Ludwig, 2009).

Our approach, by contrast, simulates belief polarization within a fully Bayesian approach, through the use of Bayesian networks, also known as Bayes nets (Pearl, 2000). The key to this approach lies in the introduction of other belief components into a Bayes net (Jern et al., 2014). In our case, we include variables such as "worldview" and trust in scientists. Worldview has been variously operationalized as people's score on a liberal-conservatism scale (Ding, Maibach, Zhao, Roser-Renouf, & Leiserowitz, 2011; McCright, Dunlap, & Xiao, 2013), or as the degree to which they endorse free markets (Heath & Gifford, 2006; Lewandowsky, Gignac, & Oberauer, 2013), or as party affiliation (Hardisty, Johnson, & Weber, 2010; Hart & Nisbet, 2011; Malka, Krosnick, & Langer, 2009), or as their position on a dichotomy between people who are "hierarchical individualists" and those who are "egalitarian-communitarian" (Kahan, Jenkins-Smith & Braman, 2011). Although those different operationalizations tap diverse aspects of people's worldview, as a first approximation, all those belief variables seem to explain an overlapping share of the variance of people's attitudes toward climate change.

Trust in climate scientists has been observed to be a driving factor behind polarization over climate change (Malka et al., 2009). Similarly, trust in experts and perception of expertise is moderated by how consonant the expert's views are with a person's own worldview (Kahan, Jenkins, et al., 2011). Accordingly, political "ideology" correlates highly with beliefs about climate change (Heath & Gifford, 2006; Kahan, Wittlin, et al., 2011; Lewandowsky, Gignac, & Vaughan, 2013; Lewandowsky, Oberauer, & Gignac, 2013; Lewandowsky et al., 2013), with people who endorse unregulated free markets being more likely to reject evidence from climate science. Even among meteorologists, a survey has found that political ideology, defined on a scale from conservative to liberal in this instance, was one of the variables most strongly related to climate views (Stenhouse, Maibach, & Cobb, 2013). By incorporating extra variables, belief polarization is potentially enabled as these additional belief variables moderate people's interpretation of the evidence. From here on, we use people's endorsement of free markets (REFs) as a concise proxy variable for their personal and political worldviews.

1.1. Bayes nets

A Bayes net is a graphical network of causally linked variables, also referred to as belief nets because the probability assigned to each variable represents the degree of belief in each state of the variable. Each variable is represented by a node in the network, while the directed lines represent dependence relationships between them. To illustrate, Bayes' theorem is represented by the Bayes net in Fig. 1a, with the evidence E having a probabilistic dependence on the hypothesis H. We assume that H can take one of two possible values, with $H = 0$ or $H = 1$, and for the sake of this example, prior probabilities $P(H = 0)=.6$ and $P(H = 1)=0.4$. We also assume, in this example, that the conditional probability $P(E = 1|H = 1)$ is 0.8. In other words, it is highly likely that if the hypothesis is true, then evidence for the hypothesis will be observed.

Suppose that such evidence has been observed, hence $P(E = 1)$ is set to 1. Bayes' theorem dictates that the updated, posterior belief $P(H = 1)$ should now be 0.73. In our

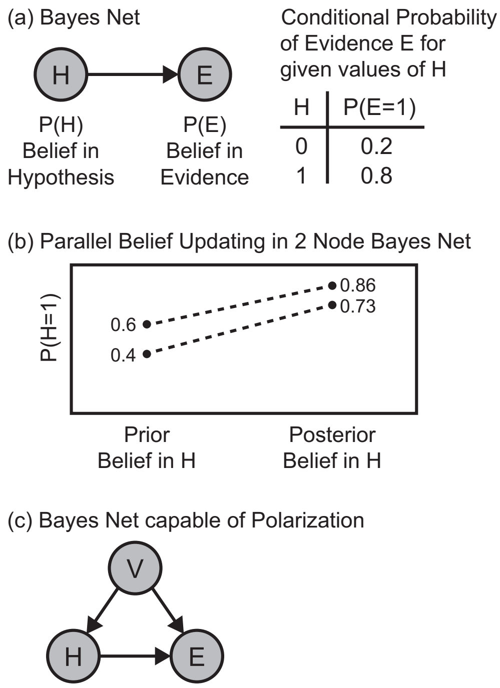

Fig. 1. (a) Bayes net visually representing Bayes' theorem with example conditional probabilities and prior/posterior belief in H. (b) Example of parallel updating in response to receiving evidence in a two-node Bayes net. (c) Bayes net configuration from Jern et al. (2014) capable of producing belief polarization.

graphical representation, this updated belief "flows backward" through the arrow in Fig. 1a and changes the probabilities of different values of *H*. This principle holds true for all Bayes nets regardless of their complexity: Each arrow captures a probabilistic (and causal) dependence, and when evidence is observed, this information "flows backward" to update the probability distribution of antecedent nodes.

Fig. 1b shows the change in belief in *H* in response to evidence, for different prior beliefs in *H*. Regardless of prior belief, belief updating is always in the same direction, consistent with the evidence. The Bayes net in Fig. 1a cannot model belief polarization: Given constant conditional probabilities, there exists no distribution of prior beliefs that could cause $P(H = 1)$ to be updated in the *opposite* direction given the observation $E = 1$.

When additional relevant variables are entered into the Bayes net, some (but not all) configurations of Bayes nets are capable of producing polarization (Jern et al., 2014). To illustrate, consider Fig. 1c. Jern et al. (2014) applied this Bayes net to Batson's (1975) study, in which participants were asked to read a story undermining Christian beliefs. Participants with strong Christian beliefs became more certain of their belief, while participants with weak Christian beliefs further weakened their beliefs. The Bayes net in Fig. 1c is able to capture this observed response with the extra variable *V* representing religious worldview, and *H* corresponding to the hypothesis that Jesus is the son of God. Jern et al. (2014) argued that a possible explanation of the Batson (1975) result is that strong believers *expect* their faith to be frequently challenged with contrary (but false) evidence, whereas someone with little religious belief expects to see evidence against religion. Hence, one's worldview influences beliefs about a hypothesis as well as one's interpretation of evidence.

1.2. Applying a Bayes net to climate change beliefs

The focal hypothesis *H* in our Bayes net was people's acceptance that humans are causing the Earth's climate to change, a view on which 97% of publishing climate scientists have converged on, based on the evidence (Anderegg et al., 2010; Cook et al., 2013; Doran & Zimmerman, 2009). The evidence variable *E,* therefore, was the scientific consensus on human-caused global warming. We chose consensus to represent evidence for several reasons: First, consensus is known to be an effective form of quasiscientific evidence in the eyes of the public at large (Petty & Wegener, 1999). Second, presentation of information about the scientific consensus has been shown to increase acceptance of climate science, demonstrating a causal link between perceived consensus and climate attitudes (Lewandowsky, Gignac, et al., 2013). Perception of consensus has been observed to be a "gateway belief," predicting numerous climate-related beliefs (Ding et al., 2011; van der Linden, Leiserowitz, Feinberg, & Maibach, 2015; McCright et al., 2013; Stenhouse et al., 2013). Third, unlike the nuanced landscape of actual scientific evidence, people's perception of the consensus among scientists can be summarized in a single number and hence is readily represented by a single node in a Bayes net.

Turning to the additional belief variables, following Jern et al.'s (2014) Bayes net 1 (b), we introduce trust (in the evidence or its source) as a third variable, represented by *T* in our Bayes net—in this case, trust in the 97% of climate scientists whose consensus constitutes the evidence node. A final significant factor influencing climate attitudes is worldview, represented by *W*. Worldview is known to influence climate attitudes (Heath & Gifford, 2006; Kahan, Wittlin et al., 2011; Lewandowsky, Oberauer, et al., 2013; Lewandowsky, Gignac, et al., 2013), which is represented by a directed link between *W* and *H*. A further directed link between *W* and *T* captures the influence of worldview on trust in climate scientists (Malka et al., 2009). We use free-market support as a proxy for worldview. Finally, *E* is linked to *H* in the standard manner, and there is an additional link between *T* and *E* representing the moderating influence of trust in belief updating. This extra link is implied in the religious belief Bayes net from Jern et al. (2014), where expectation of faith-challenging evidence (presumed false and hence untrustworthy for those with religious belief) is crucial for modeling of belief polarization. The "worldview Bayes net" shown in Fig. 2a captures the known links between our set of variables.

The relationship between variables is captured by the Bayes net's conditional probabilities in Fig. 2(b–d). Conditional probabilities will be estimated by fitting the Bayes net to the data from the experiment that is presented in this article. Fig. 2b shows approximate example values based on previous studies (Kahan, Jenkins, et al., 2011; Lewandowsky, Gignac, et al., 2013; Malka et al., 2009), and in particular the polarization model of Jern et al. (2014).

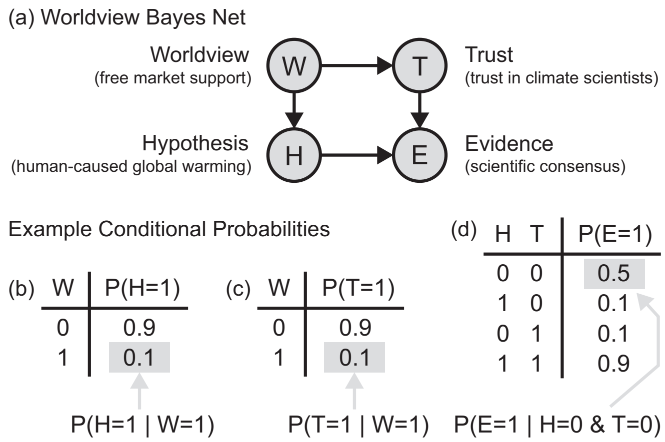

Fig. 2. (a) Worldview Bayes net. *W* represents support for free markets, *T* represents trust in climate scientists, *H* represents the hypothesis that humans are causing global warming, and *E* is the evidence for *H*: the scientific consensus on human-caused global warming. (b) Example conditional probabilities represent relationships between variables, approximately estimated based on previous studies.

The known influence of those variables on climate belief is represented in the conditional probabilities shown in Fig. 2(b and c). High free-market support [P(W = 1) approaching 1] is expected to correspond with low belief in anthropogenic global warming (AGW) [P(H = 1) approaching 0]. Similarly, high free-market support [P(W = 1) approaching 1] corresponds to low trust in climate science T [P(T = 1) approaching 0]. These conditional probabilities are labeled P(H = 1|W = 1) and P(T = 1|W = 1).

Based on these conditional probabilities, the Bayes net predicts that strong free-market supporters will decrease their belief in AGW in response to evidence for AGW. This example of contrary updating is driven largely by the conditional probability P(E = 1| T = 0 & H = 0), highlighted in Fig. 2d. This represents the expectation that evidence *for* AGW will be observed even though AGW is believed to be false. This echoes the Jern et al. (2014) interpretation of the Batson (1975) results, suggesting that the backfire effect among religious believers was driven by the expectation that their faith would be challenged with (presumably false) evidence. Suspicion about the motives of information sources has been associated with being less easily influenced by misinformation (Lewandowsky, Stritzke, Oberauer, & Morales, 2005). Similarly, extreme suspicions about scientists may predispose people to presume the existence of a (unwarranted) consensus among climate scientists, perhaps because they are conspiring to create a “hoax” (Inhofe, 2012).

By contrast, participants with low free-market support are expected to increase their belief in AGW in response to evidence for AGW, as there is no conflict between personal ideology and the evidence. The other conditional probabilities P(E = 1|T = 1 & H = 0) and P(E = 1|T = 0 & H = 1) reference low-probability outcomes, given the correlation between belief in AGW (H = 1) and trust in climate scientists (T = 1), and we do not expect them to be a significant factor. Consequently, the Bayes net can explain belief polarization based on plausible values of prior probabilities derived from the existing literature. Our experiment explores whether people polarize in response to consensus information, and by permitting estimation of the conditional probabilities underlying such belief updating, it may highlight the cognitive processes underlying polarization.

2. Method

We report an experiment that presented scientific consensus information and expert opinion to Australian and U.S. participants and measured subsequent acceptance of human-caused global warming, as well as worldview, trust in scientists, perceived consensus, and perceived expertise. The theoretical expectations of the worldview Bayes net were tested by fitting the model to the observed prior and posterior values of W, T, H, and E. In this article, single-letter variables refer to nodes in the Bayes net, while full words (e.g., Worldview, Trust) refer to experimental design variables.

2.1. Design

The experiment featured a 2×2 between-subjects design with two independent variables—a consensus intervention and an expertise intervention, which was included for exploratory reasons. By fully crossing the presence or absence of each intervention, the design featured a control group (no intervention), a consensus group (no expertise intervention), an expertise group (no consensus intervention), and a group that received a combined consensus/expert intervention. The consensus intervention (Fig. 3) featured text and an infographic explaining that there is 97% agreement among climate scientists that humans are causing global warming (Anderegg et al., 2010; Cook et al., 2013; Doran & Zimmerman, 2009). The expertise intervention featured a quote about climate change from a highly credentialed climate scientist along with a photograph of the scientist. Intervention text and survey items are available in the Supplemental Information.

2.2. Participants

The experiment was conducted online with U.S. (N = 325, conducted February 2013) and Australian (N = 400, conducted April 2013) samples. Participants were recruited via the online survey firm Qualtrics.com, which specializes in representative online surveys. Qualtrics samples their participants from a panel maintained by uSamp.com (for more details, see the uSamp.com website), using propensity sampling based on gender, age, and region, which has been shown to reasonably approximate representativeness (Berrens, Bohara, Jenkins-Smith, Silva, & Weimer, 2003). Participants were compensated with cash-equivalent points by Qualtrics. The two countries were chosen to replicate and compare results of earlier research (Ding et al., 2011; Lewandowsky, Gignac, et al., 2013; McCright & Dunlap, 2011). All survey items were compulsory. Only participants who passed attention filter questions associated with the experimental manipulations (ensuring attentive reading of intervention text) and completed all items were included in the final

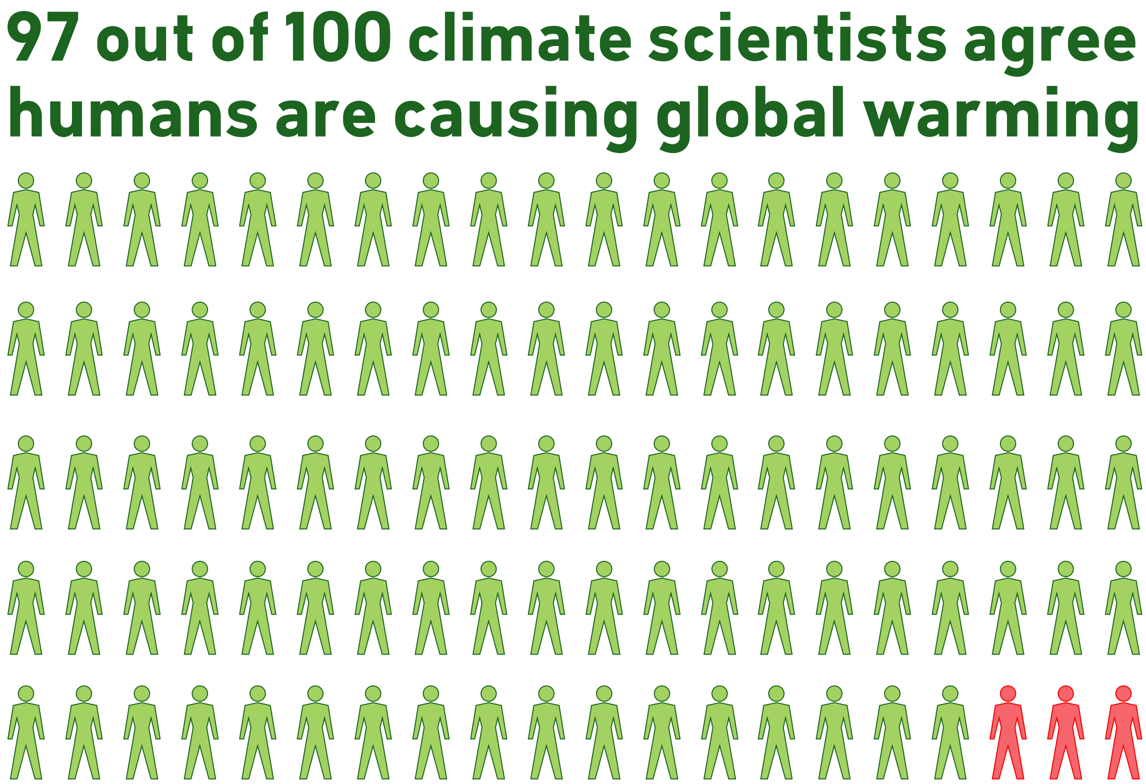

Fig. 3. Intervention text communicating scientific consensus on human-caused global warming. The 97% figure has been independently confirmed by Doran and Zimmerman (2009), Anderegg et al. (2010), and Cook et al. (2013).

sample. The overall group of participants was selected to approximate a representative sample, with participants randomly allocated to experimental conditions.

2.3. Test items

The survey comprised 33 items plus 2 attention filter questions. Six constructs were measured: worldview, trust in climate scientists, perceived expertise of scientists, perceived consensus, acceptance of AGW (Climate), and the percentage attribution of human activity to long-term climate trends. Five additional items measuring support for mitigation policies were included at the end of the Australian survey and are not analyzed in this article. Five items measuring support for free markets, developed by Heath and Gifford (2006), were used as a proxy for Worldview. Trust in climate scientists and perceived expertise of scientists used 5 items each, adapted from Ohanian (1990). Climate attitudes were measured using 5 items previously used by Lewandowsky, Gignac, et al. (2013). Attribution of human activity used 3 items representing 3 long-term climate metrics (percentage from 0 to 100% that human activity contributed to warming temperatures, sea level rise, and extreme weather events) that were also taken from Lewandowsky, Gignac, et al. (2013). Five constructs (worldview, trust, perceived expertise, AGW, attribution) were measured by averaging survey items while perceived consensus was derived from a single survey item.

3. Results

Our analysis examined the interplay between Worldview and the design variables, namely country and the consensus and expertise manipulations. Data were analyzed with R (R Development Core Team, 2011), using the Car package in R to perform an ANOVA with country and the consensus intervention as fully crossed factors and the continuous worldview variable as a further continuous predictor. All reported F-values are based on Type II sums of squares to accommodate differences in group size. Worldview was standardized to mean zero and standard deviation one.

The expertise intervention caused a small but significant increase in perceived consensus, $F(1, 717) = 6.29$, $p = 0.01$, and climate, $F(1, 717) = 5.06$, $p = 0.02$. However, the effect was additive with respect to the other experimental variables on all measures (i.e., interactions were nonsignificant, shown in Table S2). As this analysis is concerned with the interplay between worldview and the experimental manipulation, the expertise independent variable is, thus, not considered further and analysis focused on comparison of the control and consensus intervention groups.

Table 1 summarizes the influence of the independent variables (consensus intervention, country, worldview) as well as their interaction terms on five dependent variables: perceived consensus, acceptance of AGW, attribution, trust, and perceived expertise. All *p*-values and statistical information are available in the table and are not explicitly repeated in the text.

3.1. Perceived consensus

For both Australian and U.S. participants, perceived consensus in the control group averaged below 60%, consistent with other research reporting that people underestimate the scientific consensus (Nisbet & Myers, 2007). Fig. 4a and b shows that the perception of consensus varied significantly with worldview. Table 1 demonstrates a main effect of the consensus intervention on perceived consensus (control 57%, consensus intervention 91%). There was also a significant three-way interaction between worldview, the consensus intervention, and country on perceived consensus, indicating a difference between the two countries in how consensus information changes perceived consensus across the ideological spectrum. Fig. 4a shows how the increase in perceived consensus among Australian participants was highest among conservatives, while Fig. 4b shows that for Americans, the increase in perceived consensus was uniform for different levels of worldview.

3.2. Climate and attribution

The main effect of the consensus intervention was significant on both climate and attribution. The three-way interaction between worldview, country, and the consensus

Table 1
ANOVA *Results*
This table shows five separate ANOVAS on the design variables after collapsing across levels of the expertise manipulation. The dependent variable for each ANOVA is indicated in the first column

Dependent Variable	Independent Variables	η_p^2	*F*	*p*
Perceived consensus	Country	0.002	1.063	.303
	Consensus	0.298	307.358	<.001***
	Worldview	0.073	54.349	<.001***
	Country × Consensus	0.000	0.512	.475
	Country × Worldview	0.005	3.376	.067
	Consensus × Worldview	0.013	8.013	.005**
	Country × Consensus × Worldview	0.006	4.043	.045*
Climate	Country	0.000	0.088	.767
	Consensus	0.011	8.260	.004**
	Worldview	0.262	263.732	<.001***
	Country × Consensus	0.001	0.946	.331
	Country × Worldview	0.006	4.267	.039*
	Consensus × Worldview	0.000	0.356	.551
	Country × Consensus × Worldview	0.005	3.542	.060
Attribution	Country	0.003	2.486	.115
	Consensus	0.009	5.838	.016*
	Worldview	0.138	116.644	<.001***
	Country × Consensus	0.000	0.037	.848
	Country × Worldview	0.001	0.386	.534
	Consensus × Worldview	0.001	1.121	.290
	Country × Consensus × Worldview	0.006	4.148	.042*
Trust	Country	0.005	5.149	.024*
	Consensus	0.007	4.159	.042*
	Worldview	0.138	123.725	<.001***
	Country × Consensus	0.007	4.888	.027*
	Country × Worldview	0.017	12.213	<.001***
	Consensus × Worldview	0.000	.212	.645
	Country × Consensus × Worldview	0.001	.897	.344
Perceived expertise	Country	0.007	7.288	.007**
	Consensus	0.001	.778	.378
	Worldview	0.165	148.481	<.001***
	Country × Consensus	0.007	5.003	.026*
	Country × Worldview	0.008	5.392	.021*
	Consensus × Worldview	0.001	.748	.387
	Country × Consensus × Worldview	0.009	6.617	.010*

Note that independent variable "consensus" refers to the consensus experimental intervention, to be distinguished from the dependent variable "perceived consensus."
$^*p < .05$, $^{**}p < .01$, $^{***}p < .001$.

intervention was significant for attribution and close to significance for climate. Fig. 4c and e shows that for Australian participants, consensus information partially neutralized the influence of worldview on rejection of climate science. Fig. 4d and f shows that for U.S. participants, the interaction between worldview and consensus was in the opposite

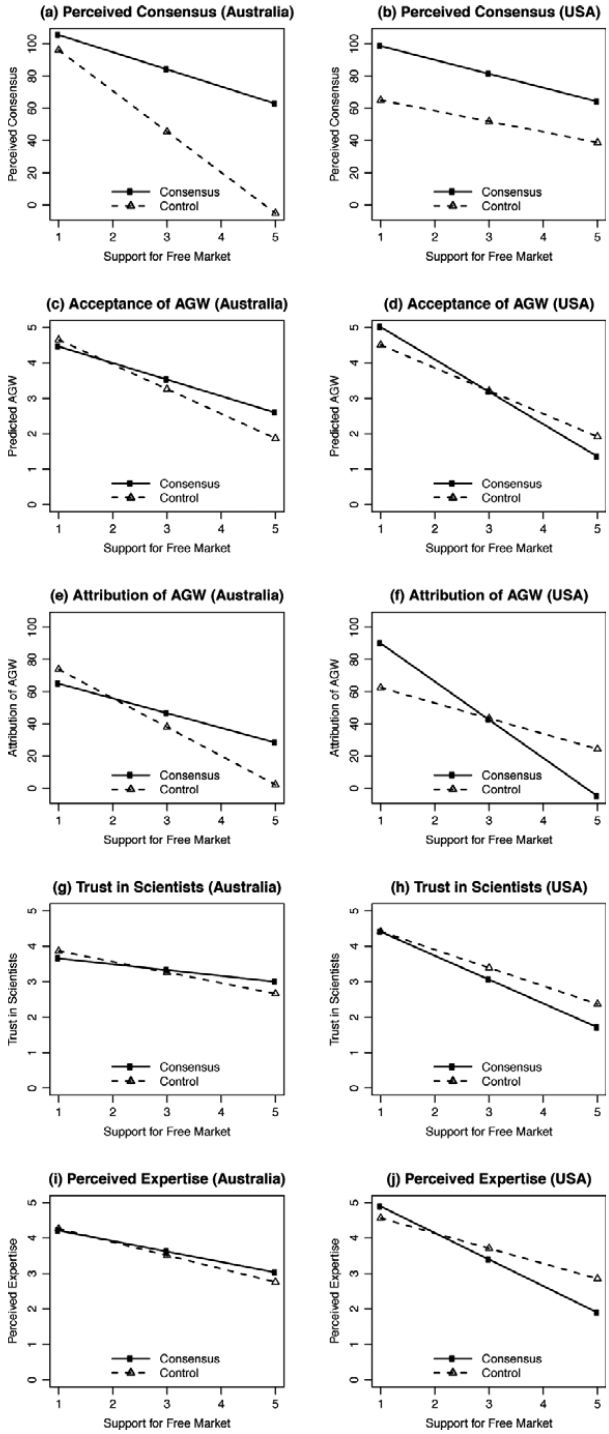

Fig. 4. Predicted response from linear regression of observed data. Triangles with dotted line represent control group, and circle with solid line represents group receiving consensus intervention. Horizontal axis represents support for free market. Left column shows Australian data, and right column shows US data. (a and b) Change in perceived consensus. (c and d) Change in belief in AGW. (e and f) Percentage attribution of AGW to long-term climate trends. (g and h) Trust in climate scientists. (i and j) Perceived expertise of climate scientists.

direction, such that greater endorsement of free markets was associated with a reduced effectiveness of the consensus intervention. This indicates that while consensus information partially neutralized worldview in Australia, in replication of Lewandowsky, Gignac, et al. (2013), it had a polarizing effect in the United States (The online supplement reports separate ANOVAS for each country that provide statistical confirmation of the statements about the data made here in the text.)

3.3. Trust and perceived expertise

Across both countries, trust in climate scientists was significantly and negatively correlated with worldview. Fig. 4g and h shows that the stronger the support for free markets, the lower the trust. The consensus intervention had a significant main effect in increasing trust. In addition, there was an interaction between the consensus intervention and country, indicating different reactions between U.S. and Australian participants. Consensus information activated further distrust of scientists among Americans with high free-market support, while the consensus intervention had no effect on trust for the Australian sample.

Perceived expertise varied significantly with worldview, consistent with the finding of Kahan, Jenkins, et al. (2011) that the perceived expertise of climate scientists is influenced by political ideology. The consensus intervention had no overall significant effect on perceived expertise. Fig. 4(i and j) shows that consensus information slightly lowered perceived expertise among Americans, except for those who were least likely to endorse unregulated free markets, whereas it had a slight positive effect among Australians.

3.4. Fitting Bayes net to observations

We fitted the worldview Bayes net to the data, which were rescaled to the range 0–1 to represent probabilities of each Bayes net variable. The Bayes net was fitted to each country's data separately, obtaining a unique set of Bayes net parameters for each country. Each participant's (rescaled) support for free market was input for W, trust in scientists for T, belief in AGW for H, and perception of consensus for E. Participants who were shown no consensus information (control condition) were used for "prior" values in the Bayes net, whereas participants shown the consensus information were used for "posterior" values. While indicated perceived consensus was used for E for control participants, E was set to 1 for posterior participants. Given that the attention filter for the consensus intervention ensured the participant remembered the actual level of consensus, the difference between setting E to 1 and using posterior data for E was negligible, and for simplicity, we, therefore, set E to 1.

The Bayes net was fitted to the data using the Bayes Toolbox in Matlab. SIMPLEX was used to minimize the RMSD discrepancy between the experimental data and the Bayes net predictions for prior and posterior W, T, H, and E. This allowed the estimation of eight parameters representing the conditional probabilities or relationship between the variables of the Bayes net, from 1,177 data points with the U.S. data and 1,400 data points with the Australian data. Note that the Bayes net minimizes the discrepancy across the group of prior and posterior data and hence does not require prior and posterior values from the same individuals.

The conditional probability obtained from the model fit that is of greatest interest is P (E = 1 | H = 0 & T = 0). This represents the expectation that there is a scientific consensus about AGW while also believing that AGW is false and while distrusting climate scientists. We interpret this probability to represent the expectation that climate scientists will "collude" to agree on human-caused global warming—thereby creating an impression of consensus—even though AGW is false. This parallels the reasoning of Jern et al. (2014), who interpreted belief polarization over challenges to religious belief to reflect believers *expecting* to encounter false evidence attacking their faith.

Fig. 5 shows the modeled prior and posterior beliefs in H (acceptance of AGW) and T (trust in climate scientists) given the estimated conditional probabilities. Within the

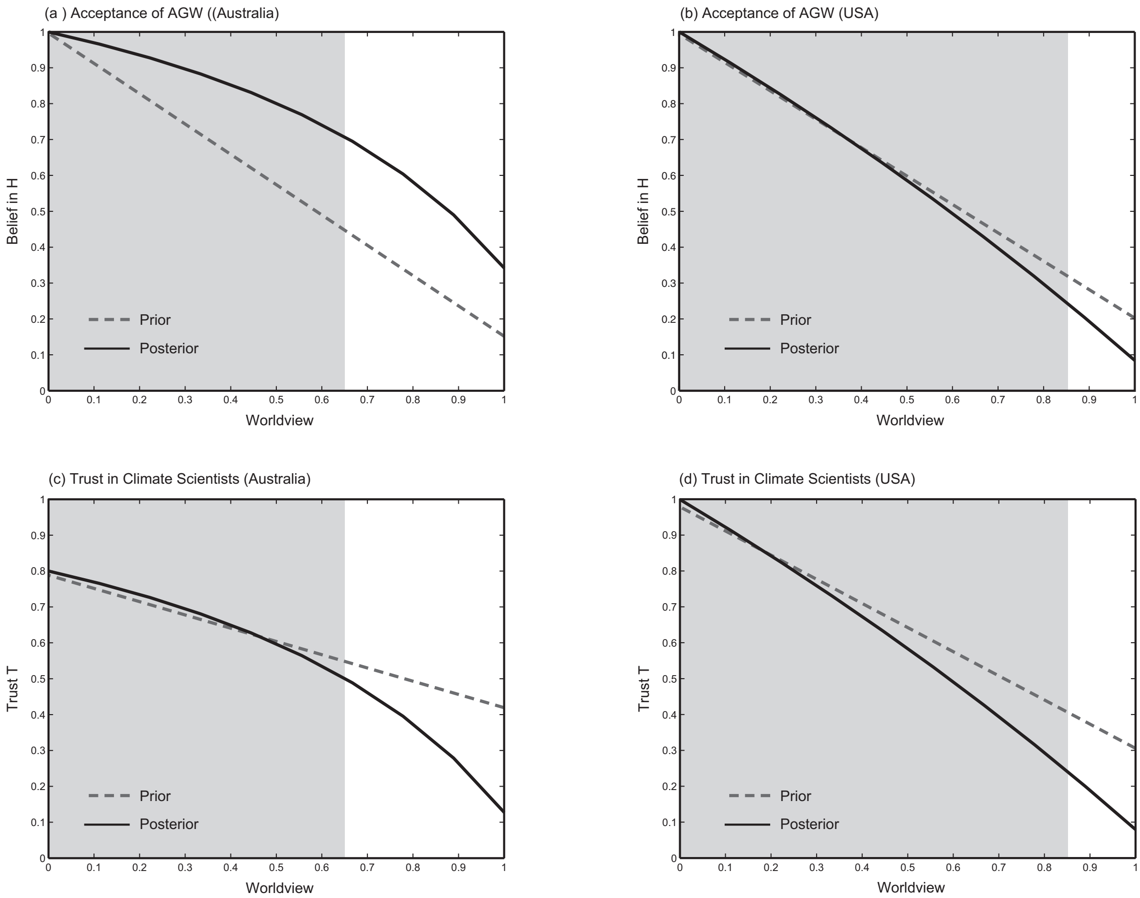

Fig. 5. Bayes net model output based on conditional probabilities estimated from data fit. Horizontal axis represents support for free market, where higher support corresponds to a more conservative worldview. Gray areas represent 95% range of the observed range of W values, demonstrating that model plots outside of gray areas represent extrapolation beyond the empirical data. (a) Belief in the hypothesis H (Australia). (b) Belief in the hypothesis H (United States). (c) Trust in climate scientists (Australia). (d) Trust in climate scientists (United States).

Bayes net, the independent variable *W* (worldview) varies from 0 (no support for free markets) to 1 (strong support for free markets). The grayed area represents the range of worldview values capturing 95% of the experimental data when they are rescaled to be commensurate with the 0–1 range required by the Bayes net. The fact that Fig. 5a and c shows smaller gray areas compared with 5b and d indicates that the Australian sample has a narrower distribution of worldview values, with fewer strong free-market supporters than in the U.S. sample. Fig. 5a captures the worldview-neutralizing effect of consensus information on the Australian sample, with a greater increase in climate belief occurring for strong supporters of free markets. In contrast, Fig. 5b captures the polarization in the U.S. sample, with strong free-market supporters showing contrary updating in response to consensus information. Fig. 5c captures the lack of change in trust for Australians over the range of observed worldview values; note that the model's extrapolation as *W* approaches 1 is well beyond the observed values of *W*. However, Fig. 5d shows the drop in trust among Americans in the observed range of *W* values.

In contrast to previous applications that presupposed the conditional probabilities of the Bayes net (Jern et al., 2014), here the relationships between the Bayes net variables were estimated empirically (see Fig. 6) and were found to be consistent with the relationships between these variables observed in previous studies. Our emphasis is not on the accuracy with which the Bayes net reproduced the observed patterns but rather on what the Bayes net can tell us about the qualitative patterns of belief updating. In particular, we focus on the fact that P(E = 1|H = 0 & T = 0) is high for the U.S. sample (.84), indicating that participants with low belief in *H* and low trust *T* (mainly people with high W, viz. political conservatives) nonetheless have a high expectation that a consensus among climate scientists exists, perhaps because they will collude to fabricate a consensus or because they engage in "groupthink." In contrast, P(E = 1|H = 0 & T = 0) was comparatively low for Australians (0.48), indicating that conservatives in the Australian sample have a lower expectation of a "fabricated" consensus.

(a) Conditional Probabilities for Study 1 (USA)

W	P(H=1)
0	0.9929
1	0.1773

W	P(T=1)
0	0.9845
1	0.2754

H	T	P(E=1)
0	0	0.8384
1	0	0.0432
0	1	0.0112
1	1	0.7650

(b) Conditional Probabilities for Study 2 (Aus)

W	P(H=1)
0	0.9961
1	0.0461

W	P(T=1)
0	0.8079
1	0.4767

H	T	P(E=1)
0	0	0.4812
1	0	0.9377
0	1	0.0000
1	1	0.9795

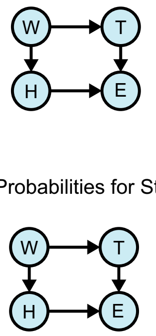

Fig. 6. Estimated conditional probabilities from fitting Bayes net to experimental data for the U.S. sample (a) and Australian sample (b).

4. Discussion

4.1. Summary of results

The present experiment replicated previous results investigating the role of worldview and perceived scientific consensus on climate beliefs. We observed that worldview is a dominant influence on climate beliefs and that providing consensus information raises perception of consensus. The detailed pattern of belief updating on the climate and attribution items differed between countries and was a function of worldview, with consensus information having a slightly worldview-neutralizing effect on Australians but a backfire effect on a small proportion of Americans with strong conservative (free-market) values.

The observed polarization among U.S. conservatives meshes with some previous results, but it stands in contrast to others. On the one hand, consensus messaging was found to have a worldview-neutralizing effect on U.S. participants in van der Linden et al. (2015), with conservatives exhibiting a greater increase in climate belief compared with liberals. One possible contributor to the contrasting result is that van der Linden uses party affiliation as a proxy for political ideology rather than free-market support as used in this study. Another contributor may be differences in the intervention content, which is significantly shorter and less informative (only mentions scientific consensus with less climate science information) in van der Linden et al. (2015) and uses different imagery (pie-chart) to communicate the consensus.

Similar to the present study, Kahan, Jenkins, et al. (2011) found that consensus information was potentially polarizing, with hierarchical individualists (i.e., mainly people who endorse free markets) attributing less expertise to climate scientists relative to egalitarian communitarians (who believe in regulated markets). The worldview-neutralizing effect on Australians that was observed here replicates existing work involving an Australian sample by Lewandowsky, Gignac, et al. (2013).

Our results also support other precedents, namely that trust in climate science is lower among conservatives (Malka et al., 2009). One novel element to our research is the observed change in trust in response to consensus information. Among Australians, trust was unchanged. Among U.S. participants, the consensus intervention polarized trust with free-market supporters becoming more distrustful of scientists when informed about the scientific consensus. We cannot offer an explanation why the two countries differ in this article. One potential limitation of our results involves the generally small effect sizes of our experimental manipulation (Table 1), especially compared with the large effect of worldview. In response, we note that the size of the effects may well be commensurate with the brevity of our manipulation: We presented participants with a brief passage and a simple graphical stimulus. We consider it remarkable that this subtle manipulation had a statistically detectable effect, however small.

4.2. Implications from Bayes net modeling

The relative success of the worldview Bayes net in capturing the response to consensus information suggests that it is possible to simulate seemingly "irrational" responses such as belief polarization as normatively rational, Bayesian responses (cf. Jern et al., 2014). Specifically, Bayesian networks show that when other prior beliefs such as trust in evidence and worldview are incorporated into belief updating models, contrary updating can be simulated under a normatively optimal framework.

Using the principal variables known to affect people's attitudes toward climate change, we found that the Bayes net could be fit to experimental data and qualitatively reproduce the pattern in the prior (control) and posterior (consensus intervention) data. By estimating the underlying conditional probabilities, the worldview Bayes net offers a possible explanation of the psychological processes driving belief polarization. The estimated conditional probabilities from the Bayes net showed that political conservatives who are dismissive of AGW exhibited an active distrust of climate scientists, with the distrust greater in the U.S. sample relative to the Australian sample. We suggest that the high distrust among U.S. conservatives is indicative of a degree of skepticism that some authors have identified as being present in conspiratorial thought (Keeley, 1999). The estimate implies that a person who does not accept AGW and distrusts scientists would, with high certainty, expect scientists to manufacture the appearance of a scientific consensus. The findings of the worldview Bayes net are, therefore, arguably consistent with previous findings of a small but significant link between the rejection of human-caused global warming and conspiratorial thinking (Lewandowsky, Oberauer, et al., 2013; Lewandowsky, Gignac, et al., 2013; Lewandowsky et al., 2015; Smith & Leiserowitz, 2012).

This study presents opportunities of further research using Bayes nets to investigate belief updating with respect to polarizing issues. One insight from the worldview Bayes net is recognition of the powerful influence of worldview on both scientific beliefs and trust in scientists. It follows that any intervention that can reduce the influence of worldview may indirectly also reduce or reverse polarization. Examples may be interventions that emphasize how scientific information is not in conflict with personal ideology by framing it in world-consonant terms (e.g., Hardisty et al., 2010) or through self-affirmation (Cohen et al., 2007).

5. Conclusions

This study has demonstrated that belief polarization can be simulated within a normatively rational framework using Bayesian networks. Fitting a Bayes net model to experimental data involving the scientific consensus on climate change indicates that contrary updating is driven by worldview, which in turn influences trust in scientific sources. Specifically, an active distrust and expectation that scientists would "manufacture" a "fake" consensus drives contrary updating among some American conservatives (van der Linden, 2013). The Bayes net model was also able to distinguish psychological differences between Australian and U.S. populations, finding that higher levels of distrust are evident in the polarized U.S. sample in contrast to the Australian sample. While Bayesian networks show that contrary updating is consistent with a normative framework, the question of whether the expectation of a manufactured scientific consensus could be considered rational is an open question.

Understanding why scientific messages lack efficacy or indeed may backfire among certain groups is of importance to scientists and science communicators, given the known role of perceived consensus as a gateway belief influencing a range of other climate attitudes (Ding et al., 2011; van der Linden et al., 2015; McCright & Dunlap, 2011; Stenhouse et al., 2013). The body of research into consensus messaging poses a complex, nuanced picture. Across both countries, consensus messaging significantly increases perceived consensus across the ideological spectrum. However, when it comes to changing other climate beliefs such as acceptance of AGW, the patterns of belief updating differ across countries. Consensus messaging is wholly positive in increasing acceptance of AGW with Australian participants, even partially neutralizing the biasing influence of worldview. While there is some evidence that consensus messaging also neutralizes ideology among U.S. participants (van der Linden et al., 2015), the present study finds evidence for belief polarization with a small number of conservatives exhibiting contrary updating.

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Supporting Information

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

Table S1. Country was assigned values 0 (United States) or 1 (Australia).

Table S2. The following table shows the Type II sums of squares ANOVA results including the expertise intervention as an independent factor crossed with other terms (the expertise intervention was excluded from the main analysis).

Table S3. ANOVA Results for United States.

Table S4. ANOVA Results for Australia.

Chapter 4
Psychological research into countering misinformation

This chapter is presented in the format of three journal article manuscripts.

Lewandowsky, S., Ecker, U. K. H., Seifert, C. M., Schwarz, N., & Cook, J. (2012). Misinformation and its correction: Continued influence and successful debiasing. *Psychological Science in the Public Interest*, *13*, 106-131.

Cook, J., Ecker, U. & Lewandowsky, S. (2015). Misinformation and how to correct it, *Emerging Trends in the Social and Behavioral Sciences*. Robert Scott and Stephen Kosslyn (Eds.), Hoboken, NJ: John Wiley and Sons.

Cook, J. (in press). Countering climate science denial and communicating scientific consensus. In M. Nisbett (Ed.), *Oxford Encyclopedia of Climate Change Communication*. London: Oxford University Press.

Foreword

Prior to 2012, there didn't exist a comprehensive, scholarly review of the misinformation literature. Lewandowsky et al. (2012) addressed this void, co-authored with a number of key scientists who had published seminal research into the psychology of misinformation. This review examined the origins and social cost of misinformation, the complex psychological processes that make debiasing so problematic and the extant research into how to effectively refute misconceptions. A companion document was The Debunking Handbook (Cook & Lewandowsky, 2011), which provided a concise summary of misinformation research, with an emphasis on practical guidelines for science communicators.

In a follow-up paper, I lead-authored an additional review of misinformation research (Cook, Ecker, & Lewandowsky, 2015), published in *Emerging Trends in the Social and Behavioral Sciences* – a review journal with an emphasis on cutting-edge and future lines of research. This paper reviewed the existing research into misinformation, with an interdisciplinary emphasis that included cognitive psychology, political science and computer science research. It also anticipated possible future lines of misinformation research.

While raising awareness of the psychological research into misinformation is important, raising awareness of the psychological research into scientific consensus is also important for effective climate communication campaigns. The high profile of the research presented in Chapter 2 led some scholars to question the value of communicating the scientific consensus. Some of the objections to consensus messaging included that it detracts from policy discussion (Pearce et al., 2015), that consensus messaging limits public discourse about climate change (Hulme, 2015) and that it is ineffective (Kahan, 2015). In response to these specific objections, I co-authored a scholarly review of the empirical research supporting the efficacy of consensus messaging that also addressed the existing objections to consensus messaging (Cook & Jacobs, 2014).

In late 2015, I was invited to contribute a chapter to the *Oxford Encyclopedia of Climate Change Communication*, on the topics of misinformation and consensus messaging. The two topics complemented well, given the primary purpose of consensus messaging is to counter misconceptions about scientific consensus, which arise in large part due to misinformation (van der Linden et al., 2016). This afforded the opportunity to publish an updated summary of the relevant research into refuting misinformation, as well as address more recent objections to consensus messaging. The chapter concluded with the recommendation that a practical way to neutralise the influence of misinformation was in an educational context, by explicitly addressing misconceptions in the classroom. This teaching approach is known as agnotology-based learning or misconception-based learning. In Chapter 6, I will outline several case-studies in agnotology-based learning.

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Misinformation and Its Correction: Continued Influence and Successful Debiasing

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Summary

The widespread prevalence and persistence of misinformation in contemporary societies, such as the false belief that there is a link between childhood vaccinations and autism, is a matter of public concern. For example, the myths surrounding vaccinations, which prompted some parents to withhold immunization from their children, have led to a marked increase in vaccine-preventable disease, as well as unnecessary public expenditure on research and public-information campaigns aimed at rectifying the situation.

We first examine the mechanisms by which such misinformation is disseminated in society, both inadvertently and purposely. Misinformation can originate from rumors but also from works of fiction, governments and politicians, and vested interests. Moreover, changes in the media landscape, including the arrival of the Internet, have fundamentally influenced the ways in which information is communicated and misinformation is spread.

We next move to misinformation at the level of the individual, and review the cognitive factors that often render misinformation resistant to correction. We consider how people assess the truth of statements and what makes people believe certain things but not others. We look at people's memory for misinformation and answer the questions of why retractions of misinformation are so ineffective in memory updating and why efforts to retract misinformation can even backfire and, ironically, increase misbelief. Though ideology and personal worldviews can be major obstacles for debiasing, there nonetheless are a number of effective techniques for reducing the impact of misinformation, and we pay special attention to these factors that aid in debiasing.

We conclude by providing specific recommendations for the debunking of misinformation. These recommendations pertain to the ways in which corrections should be designed, structured, and applied in order to maximize their impact. Grounded in cognitive psychological theory, these recommendations may help practitioners—including journalists, health professionals, educators, and science communicators—design effective misinformation retractions, educational tools, and public-information campaigns.

Keywords

misinformation, false beliefs, memory updating, debiasing

On August 4, 1961, a young woman gave birth to a healthy baby boy in a hospital at 1611 Bingham St., Honolulu. That child, Barack Obama, later became the 44th president of the United States. Notwithstanding the incontrovertible evidence for the simple fact of his American birth—from a Hawaiian birth certificate to birth announcements in local papers to the fact that his pregnant mother went into the Honolulu hospital and left it cradling a baby—a group known as "birthers" claimed Obama had been born outside the United States and was therefore not eligible to assume the presidency. Even though the claims were met with skepticism by the media, polls at the time showed that they were widely believed by a sizable proportion of the public (Travis, 2010), including a majority of voters in Republican primary elections in 2011 (Barr, 2011).

In the United Kingdom, a 1998 study suggesting a link between a common childhood vaccine and autism generated considerable fear in the general public concerning the safety of the vaccine. The UK Department of Health and several other health organizations immediately pointed to the lack of evidence for such claims and urged parents not to reject the vaccine. The

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media subsequently widely reported that none of the original claims had been substantiated. Nonetheless, in 2002, between 20% and 25% of the public continued to believe in the vaccine-autism link, and a further 39% to 53% continued to believe there was equal evidence on both sides of the debate (Hargreaves, Lewis, & Speers, 2003). More worryingly still, a substantial number of health professionals continued to believe the unsubstantiated claims (Petrovic, Roberts, & Ramsay, 2001). Ultimately, it emerged that the first author of the study had failed to disclose a significant conflict of interest; thereafter, most of the coauthors distanced themselves from the study, the journal officially retracted the article, and the first author was eventually found guilty of misconduct and lost his license to practice medicine (Colgrove & Bayer, 2005; Larson, Cooper, Eskola, Katz, & Ratzan, 2011).

Another particularly well-documented case of the persistence of mistaken beliefs despite extensive corrective efforts involves the decades-long deceptive advertising for Listerine mouthwash in the U.S. Advertisements for Listerine had falsely claimed for more than 50 years that the product helped prevent or reduce the severity of colds and sore throats. After a long legal battle, the U.S. Federal Trade Commission mandated corrective advertising that explicitly withdrew the deceptive claims. For 16 months between 1978 and 1980, the company ran an ad campaign in which the cold-related claims were retracted in 5-second disclosures midway through 30-second TV spots. Notwithstanding a $10 million budget, the campaign was only moderately successful (Wilkie, McNeill, & Mazis, 1984). Using a cross-sectional comparison of nationally representative samples at various points during the corrective campaign, a telephone survey by Armstrong, Gural, and Russ (1983) did reveal a significant reduction in consumers' belief that Listerine could alleviate colds, but overall levels of acceptance of the false claim remained high. For example, 42% of Listerine users continued to believe that the product was still promoted as an effective cold remedy, and more than half (57%) reported that the product's presumed medicinal effects were a key factor in their purchasing decision (compared with 15% of consumers of a competing product).

Those results underscore the difficulties of correcting widespread belief in misinformation. These difficulties arise from two distinct factors. First, there are cognitive variables within each person that render misinformation "sticky." We focus primarily on those variables in this article. The second factor is purely pragmatic, and it relates to the ability to reach the target audience. The real-life Listerine quasi-experiment is particularly informative in this regard, because its effectiveness was limited even though the company had a fairly large budget for disseminating corrective information.

What causes the persistence of erroneous beliefs in sizable segments of the population? Assuming corrective information has been received, why does misinformation[1] continue to influence people's thinking despite clear retractions? The literature on these issues is extensive and complex, but it permits several reasonably clear conclusions, which we present in the remainder of this article. Psychological science has much light to shed onto the cognitive processes with which individuals process, acquire, and update information.

We focus primarily on individual-level cognitive processes as they relate to misinformation. However, a discussion of the continued influence of misinformation cannot be complete without addressing the societal mechanisms that give rise to the persistence of false beliefs in large segments of the population. Understanding why one might reject evidence about President Obama's place of birth is a matter of individual cognition; however, understanding why more than half of Republican primary voters expressed doubt about the president's birthplace (Barr, 2011) requires a consideration of not only why individuals cling to misinformation, but also how information—especially false information—is disseminated through society. We therefore begin our analysis at the societal level, first by highlighting the societal costs of widespread misinformation, and then by turning to the societal processes that permit its spread.

The Societal Cost of Misinformation

It is a truism that a functioning democracy relies on an educated and well-informed populace (Kuklinski, Quirk, Jerit, Schwieder, & Rich, 2000). The processes by which people form their opinions and beliefs are therefore of obvious public interest, particularly if major streams of beliefs persist that are in opposition to established facts. If a majority believes in something that is factually incorrect, the misinformation may form the basis for political and societal decisions that run counter to a society's best interest; if individuals are misinformed, they may likewise make decisions for themselves and their families that are not in their best interest and can have serious consequences. For example, following the unsubstantiated claims of a vaccination-autism link, many parents decided not to immunize their children, which has had dire consequences for both individuals and societies, including a marked increase in vaccine-preventable disease and hence preventable hospitalizations, deaths, and the unnecessary expenditure of large amounts of money for follow-up research and public-information campaigns aimed at rectifying the situation (Larson et al., 2011; Poland & Spier, 2010; Ratzan, 2010).

Reliance on misinformation differs from ignorance, which we define as the *absence* of relevant knowledge. Ignorance, too, can have obvious detrimental effects on decision making, but, perhaps surprisingly, those effects may be less severe than those arising from reliance on misinformation. Ignorance may be a lesser evil because in the self-acknowledged absence of knowledge, people often turn to simple heuristics when making decisions. Those heuristics, in turn, can work surprisingly well, at least under favorable conditions. For example, mere familiarity with an object often permits people to make accurate guesses about it (Goldstein & Gigerenzer, 2002; Newell & Fernandez, 2006). Moreover, people typically have relatively low levels of confidence in decisions made solely on the basis of such heuristics (De Neys, Cromheeke, & Osman, 2011; Glöckner & Bröder, 2011). In other words, ignorance rarely leads to strong support for a cause, in contrast to false beliefs based on misinformation, which are often held strongly and with (perhaps infectious) conviction. For example, those who most vigorously reject the scientific evidence for climate change are also those who believe they are best informed about the subject (Leiserowitz, Maibach, Roser-Renouf, & Hmielowski, 2011).

The costs of misinformation to society are thus difficult to ignore, and its widespread persistence calls for an analysis of its origins.

Origins of Misinformation

Misinformation can be disseminated in a number of ways, often in the absence of any intent to mislead. For example, the timely news coverage of unfolding events is by its very nature piecemeal and requires occasional corrections of earlier statements. As a case in point, the death toll after a major natural disaster—such as the 2011 tsunami in Japan—is necessarily updated until a final estimate becomes available. Similarly, a piece of information that is considered "correct" at any given stage can later turn out to have been erroneous.

Indeed, this piecemeal approach to knowledge construction is the very essence of the scientific process, through which isolated initial findings are sometimes refuted or found not to be replicable. It is for this reason that scientific conclusions are usually made and accepted only after some form of consensus has been reached on the basis of multiple lines of converging evidence. Misinformation that arises during an evolving event or during the updating of knowledge is unavoidable as well as unintentional; however, there are other sources of misinformation that are arguably less benign. The particular sources we discuss in this article are:

- Rumors and fiction. Societies have struggled with the misinformation-spreading effects of rumors for centuries, if not millennia; what is perhaps less obvious is that even works of fiction can give rise to lasting misconceptions of the facts.
- Governments and politicians. Governments and politicians can be powerful sources of misinformation, whether inadvertently or by design.
- Vested interests. Corporate interests have a long and well-documented history of seeking to influence public debate by promulgating incorrect information. At least on some recent occasions, such systematic campaigns have also been directed *against* corporate interests, by nongovernmental interest groups.
- The media. Though the media are by definition seeking to inform the public, it is notable that they are particularly prone to spreading misinformation for systemic reasons that are worthy of analysis and exposure. With regard to new media, the Internet has placed immense quantities of information at our fingertips, but it has also contributed to the spread of misinformation. The growing use of social networks may foster the quick and wide dissemination of misinformation. The fractionation of the information landscape by new media is an important contributor to misinformation's particular resilience to correction.

We next consider each of these sources in turn.

Rumors and fiction

Rumors and urban myths constitute important sources of misinformation. For example, in 2006, a majority of Democrats believed that the George W. Bush administration either assisted in the 9/11 terror attacks or took no action to stop them (Nyhan, 2010). This widespread belief is all the more remarkable because the conspiracy theory found virtually no traction in the mainstream media.

Human culture strongly depends on people passing on information. Although the believability of information has been identified as a factor determining whether it is propagated (Cotter, 2008), people seem to mainly pass on information that will evoke an emotional response in the recipient, irrespective of the information's truth value. Emotional arousal in general increases people's willingness to pass on information (Berger, 2011). Thus, stories containing content likely to evoke disgust, fear, or happiness are spread more readily from person to person and more widely through social media than are neutral stories (Cotter, 2008; Heath, Bell, & Sternberg, 2001; K. Peters, Kashima, & Clark, 2009). Accordingly, the most effective "misinformers" about vaccines are parents who truly believe that their child has been injured by a vaccine. When such individuals present their mistaken beliefs as fact, their claims may be discussed on popular TV and radio talk shows and made the subject of TV dramas and docudramas (Myers & Pineda, 2009).

A related but perhaps more surprising source of misinformation is literary fiction. People extract knowledge even from sources that are explicitly identified as fictional. This process is often adaptive, because fiction frequently contains valid information about the world. For example, non-Americans' knowledge of U.S. traditions, sports, climate, and geography partly stems from movies and novels, and many Americans know from movies that Britain and Australia have left-hand traffic. By definition, however, fiction writers are not obliged to stick to the facts, which creates an avenue for the spread of misinformation, even by stories that are explicitly identified as fictional. A study by Marsh, Meade, and Roediger (2003) showed that people relied on misinformation acquired from clearly fictitious stories to respond to later quiz questions, even when these pieces of misinformation contradicted common knowledge. In most cases, source attribution was intact, so people were aware that their answers to the quiz questions were based on information from the stories, but reading the stories also increased people's illusory belief of prior knowledge. In other words, encountering misinformation in a fictional context led people to assume they had known it all along and to integrate this misinformation with their prior knowledge (Marsh & Fazio, 2006; Marsh et al., 2003).

The effects of fictional misinformation have been shown to be stable and difficult to eliminate. Marsh and Fazio (2006) reported that prior warnings were ineffective in reducing the acquisition of misinformation from fiction, and that acquisition was only reduced (not eliminated) under conditions of active on-line monitoring—when participants were instructed to actively monitor the contents of what they were reading and to press a key every time they encountered a piece of misinformation (see also Eslick, Fazio, & Marsh, 2011). Few people would be so alert and mindful when reading fiction for enjoyment. These links between fiction and incorrect knowledge are particularly concerning when popular fiction pretends to accurately portray science but fails to do so, as was the case with Michael Crichton's novel *State of Fear*. The novel misrepresented the science of global climate change but was nevertheless introduced as "scientific" evidence into a U.S. Senate committee (Allen, 2005; Leggett, 2005).

Writers of fiction are expected to depart from reality, but in other instances, misinformation is manufactured intentionally. There is considerable peer-reviewed evidence pointing to the fact that misinformation can be intentionally or carelessly disseminated, often for political ends or in the service of vested interests, but also through routine processes employed by the media.

Governments and politicians

In the lead-up to the U.S.-led invasion of Iraq in 2003, U.S. government officials proclaimed there was no doubt that Saddam Hussein had weapons of mass destruction (WMDs) and was ready to use them against his enemies. The Bush administration also juxtaposed Iraq and the 9/11 terrorist attacks, identifying Iraq as the frontline in the "War on Terror" (Reese & Lewis, 2009) and implying that it had intelligence linking Iraq to al-Qaida. Although no WMDs were ever found in Iraq and its link to al-Qaida turned out to be unsubstantiated, large segments of the U.S. public continued to believe the administration's earlier claims, with some 20% to 30% of Americans believing that WMDs had actually been discovered in Iraq years after the invasion (Kull, Ramsay, & Lewis, 2003; Kull et al., 2006) and around half of the public endorsing links between Iraq and al-Qaida (Kull et al., 2006). These mistaken beliefs persisted even though all tentative media reports about possible WMD sightings during the invasion were followed by published corrections, and even though the nonexistence of WMDs in Iraq and the absence of links between Iraq and al-Qaida was eventually widely reported and became the official bipartisan U.S. position through the Duelfer report.

Politicians were also a primary source of misinformation during the U.S. health care debate in 2009. Misinformation about the Obama health plan peaked when Sarah Palin posted a comment about "death panels" on her Facebook page. Within 5 weeks, 86% of Americans had heard the death-panel claim. Of those who heard the myth, fully half either believed it or were not sure of its veracity. *Time* magazine reported that the single phrase "death panels" nearly derailed Obama's health care plan (Nyhan, 2010).

Although Sarah Palin's turn of phrase may have been spontaneous and its consequences unplanned, analyses have revealed seemingly systematic efforts to misinform the public—for example, about climate change (McCright & Dunlap, 2010). During the administration of President George W. Bush, political appointees demonstrably interfered with scientific assessments of climate change (e.g., Mooney, 2007), and NASA's inspector general found in 2008 that in previous years, the agency's "Office of Public Affairs managed the topic of climate change in a manner that reduced, marginalized, or mischaracterized climate change science made available to the general public" (Winters, 2008, p. 1).

The public seems to have some awareness of the presence of politically motivated misinformation in society, especially during election campaigns (Ramsay, Kull, Lewis, & Subias, 2010). However, when asked to identify specific instances of such misinformation, people are often unable to differentiate between information that is false and other information that is correct (Ramsay et al., 2010). Thus, public awareness of the problem is no barrier to widespread and lasting confusion.

Vested interests and nongovernmental organizations (NGOs)

There is also evidence of concerted efforts by vested interests to disseminate misinformation, especially when it comes to issues of the environment (e.g., Jacques, Dunlap, & Freeman, 2008) and public health (e.g., Oreskes & Conway, 2010; Proctor, 2008) that have the potential to motivate policies that would impose a regulatory burden on certain industries (e.g., tobacco manufacturers or the fossil-fuel industry). This process of willful manufacture of mistaken beliefs has been described as "agnogenesis" (Bedford, 2010). There is considerable legal and scientific evidence for this process in at least two arenas—namely, industry-based responses to the health consequences of smoking and to climate change.

In 2006, a U.S. federal court ruled that major domestic cigarette manufacturers were guilty of conspiring to deny, distort, and minimize the hazards of cigarette smoking (Smith et al., 2011). Similarly, starting in the early 1990s, the American Petroleum Institute, the Western Fuels Association (a coal-fired electrical industry consortium), and The Advancement of Sound Science Coalition (TASSC; a group sponsored by Philip Morris) drafted and promoted campaigns to cast doubt on the science of climate change (Hoggan, Littlemore, &

Littlemore, 2009). These industry groups have also formed an alliance with conservative think tanks, using a handful of scientists (typically experts from a different domain) as spokespersons (Oreskes & Conway, 2010). Accordingly, more than 90% of books published between 1972 and 2005 that expressed skepticism about environmental issues have been linked to conservative think tanks (Jacques et al., 2008).

However, the spreading of misinformation is by no means always based on concerted efforts by vested interests. On the contrary, industry itself has been harmed by misinformation in some instances. For example, the vaccination-autism myth has led to decreased vaccination rates (Owens, 2002; Poland & Jacobsen, 2011) and hence arguably decreased the revenue and profits of pharmaceutical companies. A similar case can be made for genetically modified (GM) foods, which are strongly opposed by sizable segments of the public, particularly in Europe (e.g., Gaskell et al., 2003; Mielby, Sandøe, & Lassen, 2012). The magnitude of opposition to GM foods seems disproportionate to their actual risks as portrayed by expert bodies (e.g., World Health Organization, 2005), and it appears that people often rely on NGOs, such as Greenpeace, that are critical of peer-reviewed science on the issue to form their opinions about GM foods (Einsele, 2007). These alternative sources have been roundly criticized for spreading misinformation (e.g., Parrott, 2010).

Media

Given that people largely obtain their information from the media (broadly defined to include print newspapers and magazines, radio, TV, and the Internet), the media's role in the dissemination of misinformation deserves to be explored. We have already mentioned that the media sometimes unavoidably report incorrect information because of the need for timely news coverage. There are, however, several other systemic reasons for why the media might get things wrong.

First, the media can inadvertently oversimplify, misrepresent, or overdramatize scientific results. Science is complex, and for the layperson, the details of many scientific studies are difficult to understand or of marginal interest. Science communication therefore requires simplification in order to be effective. Any oversimplification, however, can lead to misunderstanding. For example, after a study forecasting future global extinctions as a result of climate change was published in *Nature*, it was widely misrepresented by news media reports, which made the consequences seem more catastrophic and the timescale shorter than actually projected (Ladle, Jepson, & Whittaker, 2005). These mischaracterizations of scientific results imply that scientists need to take care to communicate their results clearly and unambiguously, and that press releases need to be meticulously constructed to avoid misunderstandings by the media (e.g., Riesch & Spiegelhalter, 2011).

Second, in all areas of reporting, journalists often aim to present a "balanced" story. In many instances, it is indeed appropriate to listen to both sides of a story; however, if media stick to journalistic principles of "balance" even when it is not warranted, the outcome can be highly misleading (Clarke, 2008). For example, if the national meteorological service issued a severe weather warning for tomorrow, no one would—or should—be interested in their neighbor Jimmy's opinion that it will be a fine day. For good reasons, a newspaper's weather forecast relies on expert assessment and excludes lay opinions.

On certain hotly contested issues, there is evidence that the media have systematically overextended the "balance" frame. For example, the overwhelming majority (more than 95%; Anderegg, Prall, Harold, & Schneider, 2010; Doran & Zimmerman, 2009) of actively publishing climate scientists agree on the fundamental facts that the globe is warming and that this warming is due to greenhouse-gas emissions caused by humans; yet the contrarian opinions of nonexperts are featured prominently in the media (Boykoff & Boykoff, 2004). A major Australian TV channel recently featured a self-styled climate "expert" whose diverse qualifications included authorship of a book on cat palmistry (Readfearn, 2011). This asymmetric choice of "experts" leads to the perception of a debate about issues that were in fact resolved in the relevant scientific literature long ago.

Although these systemic problems are shared to varying extents by most media outlets, the problems vary considerably both across time and among outlets. In the U.S., expert voices have repeatedly expressed alarm at the decline in "hard" news coverage since the 1990s and the growth of sensationalist coverage devoid of critical analysis or in-depth investigation (e.g., Bennett, 2003). After the invasion of Iraq in 2003, the American media attracted much censure for their often uncritical endorsement of prewar claims by the Bush administration about Iraqi WMDs (e.g., Artz & Kamalipour, 2004, Kamalipour & Snow, 2004; Rampton & Stauber, 2003, Tiffen, 2009), although there was considerable variation among outlets in the accuracy of their coverage, as revealed by survey research into the persistence of misinformation. Stephen Kull and his colleagues (e.g., Kull et al., 2003) have repeatedly shown that the level of belief in misinformation among segments of the public varies dramatically according to preferred news outlets, running along a continuum from Fox News (whose viewers are the most misinformed on most issues) to National Public Radio (whose listeners are the least misinformed overall).

The role of the Internet. The Internet has revolutionized the availability of information; however, it has also facilitated the spread of *mis*information because it obviates the use of conventional "gate-keeping" mechanisms, such as professional editors. This is particularly the case with the development of Web 2.0, whereby Internet users have moved from being passive consumers of information to actively creating content on Web sites such as Twitter and YouTube or blogs.

People who use new media, such as blogs (McCracken, 2011), to source their news report that they find them fairer, more credible, and more in-depth than traditional sources (T. J. Johnson & Kaye, 2004). Blog users judged war blogs to be more credible sources for news surrounding the conflicts in Iraq and Afghanistan than traditional media (T. J. Johnson & Kaye, 2010).

On the other hand, information on the Internet can be highly misleading, and it is progressively replacing expert advice. For example, people are increasingly sourcing health care information from social networks. In 2009, 61% of American adults looked online for health information (Fox & Jones, 2009). Relying on the Internet as a source of health information is fraught with risk because its reliability is highly variable. Among the worst performers in terms of accuracy are dietary Web sites: A survey of the first 50 Web sites matching the search term "weight loss diets" revealed that only 3 delivered sound dietary advice (Miles, Petrie, & Steel, 2000). Other domains fare more favorably: A survey of English-language Web sites revealed that 75% of sites on depression were completely accurate and that 86% of obesity-related Web sites were at least partially accurate (Berland et al., 2001).

Online videos are an effective and popular means of disseminating information (and misinformation)—1.2 billion people viewed online videos in October 2011 (Radwanick, 2011). A survey of 153 YouTube videos matching the search terms "vaccination" and "immunization" revealed that approximately half of the videos were not explicitly supportive of immunization, and that the information in the anti-immunization videos often contradicted official reference material (Keelan, Pavri-Garcia, Tomlinson, & Wilson, 2007). A survey of YouTube videos about the H1N1 influenza pandemic revealed that 61.3% of the videos contained useful information about the disease, whereas 23% were misleading (Pandey, Patni, Singh, Sood, & Singh, 2010).

Finally, there are hoax Web sites whose sole purpose is to disseminate misinformation. Although these sites can have many objectives, including parody, the more dangerous sites pass themselves off as official sources of information. For instance, the site martinlutherking.org (created by a White-power organization) disseminates hateful information about Dr. Martin Luther King while pretending to be an official King Web site (Piper, 2000).

Consequences of increasing media fractionation. The growth of cable TV, talk radio, and the Internet have made it easier for people to find news sources that support their existing views, a phenomenon known as *selective exposure* (Prior, 2003). When people have more media options to choose from, they are more biased toward like-minded media sources. The emergence of the Internet in particular has led to a fractionation of the information landscape into "echo chambers"—that is, (political) blogs that primarily link to other blogs of similar persuasion and not to those with opposing viewpoints. More than half of blog readers seek out blogs that support their views, whereas only 22% seek out blogs espousing opposing views, a phenomenon that has led to the creation of "cyber-ghettos" (T. J. Johnson, Bichard, & Zhang, 2009). These cyber-ghettos have been identified as one reason for the increasing polarization of political discourse (McCright, 2011; Stroud, 2010).

One consequence of a fractionated information landscape is the emergence of "strategic extremism" among politicians (Glaeser, Ponzetto, & Shapiro, 2005). Although politicians have traditionally vied for the attention of the political center, extremism can be strategically effective if it garners more votes at one extreme of the political spectrum than it loses in the center or the opposite end of the spectrum. A precondition for the success—defined as a net gain of votes—of strategic extremism is a fractionated media landscape in which information (or an opinion) can be selectively channeled to people who are likely to support it, without alienating others. The long-term effects of such strategic extremism, however, may well include a pernicious and prolonged persistence of misinformation in large segments of society, especially when such information leaks out of cyber-ghettos into the mainstream. This fractionation of the information landscape is important in that, as we show later in this article, worldview plays a major role in people's resistance to corrections of misinformation.

From Individual Cognition to Debiasing Strategies

We now turn to the individual-level cognitive processes that are involved in the acquisition and persistence of misinformation. In the remainder of the article, we address the following points:

We begin by considering how people assess the truth of a statement: What makes people believe certain things, but not others?

Once people have acquired information and believe in it, why do corrections and retractions so often fail? Worse yet, why can attempts at retraction backfire, entrenching belief in misinformation rather than reducing it?

After addressing these questions, we survey the successful techniques by which the impact of misinformation can be reduced.

We then discuss how, in matters of public and political import, people's personal worldviews, or ideology, can play a crucial role in preventing debiasing, and we examine how these difficulties arise and whether they can be overcome.

Finally, we condense our discussion into specific recommendations for practitioners and consider some ethical implications and practical limitations of debiasing efforts in general.

Assessing the Truth of a Statement: Recipients' Strategies

Misleading information rarely comes with a warning label. People usually cannot recognize that a piece of information is incorrect until they receive a correction or retraction. For better or worse, the acceptance of information as true is favored by tacit norms of everyday conversational conduct: Information relayed in conversation comes with a "guarantee of relevance" (Sperber & Wilson, 1986), and listeners proceed on the assumption that speakers try to be truthful, relevant, and clear, unless evidence to the contrary calls this default into question (Grice, 1975; Schwarz, 1994, 1996). Some research has even suggested that to comprehend a statement, people must at least temporarily accept it as true (Gilbert, 1991). On this view, belief is an inevitable consequence of—or, indeed, precursor to—comprehension.

Although suspension of belief is possible (Hasson, Simmons, & Todorov, 2005; Schul, Mayo, & Burnstein, 2008), it seems to require a high degree of attention, considerable implausibility of the message, or high levels of distrust at the time the message is received. So, in most situations, the deck is stacked in favor of accepting information rather than rejecting it, provided there are no salient markers that call the speaker's intention of cooperative conversation into question. Going beyond this default of acceptance requires additional motivation and cognitive resources: If the topic is not very important to you, or you have other things on your mind, misinformation will likely slip in.

When people do thoughtfully evaluate the truth value of information, they are likely to attend to a limited set of features. First, is this information compatible with other things I believe to be true? Second, is this information internally coherent?—do the pieces form a plausible story? Third, does it come from a credible source? Fourth, do other people believe it? These questions can be answered on the basis of declarative or experiential information—that is, by drawing on one's knowledge or by relying on feelings of familiarity and fluency (Schwarz, 2004; Schwarz, Sanna, Skurnik, & Yoon, 2007). In the following section, we examine those issues.

Is the information compatible with what I believe?

As numerous studies in the literature on social judgment and persuasion have shown, information is more likely to be accepted by people when it is consistent with other things they assume to be true (for reviews, see McGuire, 1972; Wyer, 1974). People assess the logical compatibility of the information with other facts and beliefs. Once a new piece of knowledge-consistent information has been accepted, it is highly resistant to change, and the more so the larger the compatible knowledge base is. From a judgment perspective, this resistance derives from the large amount of supporting evidence (Wyer, 1974); from a cognitive-consistency perspective (Festinger, 1957), it derives from the numerous downstream inconsistencies that would arise from rejecting the prior information as false. Accordingly, compatibility with other knowledge increases the likelihood that misleading information will be accepted, and decreases the likelihood that it will be successfully corrected.

When people encounter a piece of information, they can check it against other knowledge to assess its compatibility. This process is effortful, and it requires motivation and cognitive resources. A less demanding indicator of compatibility is provided by one's meta-cognitive experience and affective response to new information. Many theories of cognitive consistency converge on the assumption that information that is inconsistent with one's beliefs elicits negative feelings (Festinger, 1957). Messages that are inconsistent with one's beliefs are also processed less fluently than messages that are consistent with one's beliefs (Winkielman, Huber, Kavanagh, & Schwarz, 2012). In general, fluently processed information feels more familiar and is more likely to be accepted as true; conversely, disfluency elicits the impression that something doesn't quite "feel right" and prompts closer scrutiny of the message (Schwarz et al., 2007; Song & Schwarz, 2008). This phenomenon is observed even when the fluent processing of a message merely results from superficial characteristics of its presentation. For example, the same statement is more likely to be judged as true when it is printed in high rather than low color contrast (Reber & Schwarz, 1999), presented in a rhyming rather than nonrhyming form (McGlone & Tofighbakhsh, 2000), or delivered in a familiar rather than unfamiliar accent (Levy-Ari & Keysar, 2010). Moreover, misleading questions are less likely to be recognized as such when printed in an easy-to-read font (Song & Schwarz, 2008).

As a result, analytic as well as intuitive processing favors the acceptance of messages that are compatible with a recipient's preexisting beliefs: The message contains no elements that contradict current knowledge, is easy to process, and "feels right."

Is the story coherent?

Whether a given piece of information will be accepted as true also depends on how well it fits a broader story that lends sense and coherence to its individual elements. People are particularly likely to use an assessment strategy based on this principle when the meaning of one piece of information cannot be assessed in isolation because it depends on other, related pieces; use of this strategy has been observed in basic research on mental models (for a review, see Johnson-Laird, 2012), as well as extensive analyses of juries' decision making (Pennington & Hastie, 1992, 1993).

A story is compelling to the extent that it organizes information without internal contradictions in a way that is compatible with common assumptions about human motivation and behavior. Good stories are easily remembered, and gaps are filled with story-consistent intrusions. Once a coherent story has been formed, it is highly resistant to change: Within the story, each element is supported by the fit of other elements, and any alteration of an element may be made implausible by the downstream inconsistencies it would cause. Coherent stories are easier to process than incoherent stories are

(Johnson-Laird, 2012), and people draw on their processing experience when they judge a story's coherence (Topolinski, 2012), again giving an advantage to material that is easy to process.

Is the information from a credible source?

When people lack the motivation, opportunity, or expertise to process a message in sufficient detail, they can resort to an assessment of the communicator's credibility. Not surprisingly, the persuasiveness of a message increases with the communicator's perceived credibility and expertise (for reviews, see Eagly & Chaiken, 1993; Petty & Cacioppo, 1986). However, even untrustworthy sources are often influential. Several factors contribute to this observation. People are often insensitive to contextual cues that bear on the credibility of a source. For example, expert testimony has been found to be similarly persuasive whether it is provided under oath or in another context (Nyhan, 2011). Similarly, Cho, Martens, Kim, and Rodrigue (2011) found that messages denying climate change were similarly influential whether recipients were told they came from a study "funded by Exxon" or from a study "funded from donations by people like you." Such findings suggest that situational indicators of credibility may often go unnoticed, consistent with people's tendency to focus on features of the actor rather than the situation (Ross, 1977). In addition, the gist of a message is often more memorable than its source, and an engaging story from an untrustworthy source may be remembered and accepted long after the source has been forgotten (for a review of such "sleeper effects," see Eagly & Chaiken, 1993).

People's evaluation of a source's credibility can be based on declarative information, as in the above examples, as well as experiential information. The mere repetition of an unknown name can cause it to seem familiar, making its bearer "famous overnight" (Jacoby, Kelley, Brown, & Jaseschko, 1989)—and hence more credible. Even when a message is rejected at the time of initial exposure, that initial exposure may lend it some familiarity-based credibility if the recipient hears it again.

Do others believe this information?

Repeated exposure to a statement is known to increase its acceptance as true (e.g., Begg, Anas, & Farinacci, 1992; Hasher, Goldstein, & Toppino, 1977). In a classic study of rumor transmission, Allport and Lepkin (1945) observed that the strongest predictor of belief in wartime rumors was simple repetition. Repetition effects may create a perceived social consensus even when no consensus exists. Festinger (1954) referred to social consensus as a "secondary reality test": If many people believe a piece of information, there's probably something to it. Because people are more frequently exposed to widely shared beliefs than to highly idiosyncratic ones, the familiarity of a belief is often a valid indicator of social consensus. But, unfortunately, information can seem familiar for the wrong reason, leading to erroneous perceptions of high consensus. For example, Weaver, Garcia, Schwarz, and Miller (2007) exposed participants to multiple iterations of the same statement, provided by the same communicator. When later asked to estimate how widely the conveyed belief is shared, participants estimated consensus to be greater the more often they had read the identical statement from the same, single source. In a very real sense, a single repetitive voice can sound like a chorus.

Social-consensus information is particularly powerful when it pertains to one's reference group (for a review, see Krech, Crutchfield, & Ballachey, 1962). As already noted, this renders repetition in the echo chambers of social-media networks particularly influential. One possible consequence of such repetition is *pluralistic ignorance*, or a divergence between the actual prevalence of a belief in a society and what people in that society think others believe. For example, in the lead-up to the invasion of Iraq in 2003, voices that advocated unilateral military action were given prominence in the American media, which caused the large *majority* of citizens who actually wanted the U.S. to engage multilaterally, in concert with other nations, to feel that they were in the minority (Leviston & Walker, 2011; Todorov & Mandisodza, 2004). Conversely, the minority of citizens who advocated unilateral action incorrectly felt that they were in the majority (this *false-consensus effect* is the flip side of pluralistic ignorance).

The extent of pluralistic ignorance (or of the false-consensus effect) can be quite striking: In Australia, people with particularly negative attitudes toward Aboriginal Australians or asylum seekers have been found to overestimate public support for their attitudes by 67% and 80%, respectively (Pedersen, Griffiths, & Watt, 2008). Specifically, although only 1.8% of people in a sample of Australians were found to hold strongly negative attitudes toward Aboriginals, those few individuals thought that 69% of all Australians (and 79% of their friends) shared their fringe beliefs. This represents an extreme case of the false-consensus effect.

Perceived social consensus can serve to solidify and maintain belief in misinformation. But how do the processes we have reviewed affect people's ability to correct misinformation? From the perspective of truth assessment, corrections involve a competition between the perceived truth value of misinformation and correct information. In the ideal case, corrections undermine the perceived truth of misinformation and enhance the acceptance of correct information. But as we discuss in the next section, corrections often fail to work as expected. It is this failure of corrections, known as the *continued influence effect* (H. M. Johnson & Seifert, 1994), that constitutes the central conundrum in research on misinformation.

The Continued Influence Effect: Retractions Fail to Eliminate the Influence of Misinformation

We first consider the cognitive parameters of credible retractions in neutral scenarios, in which people have no inherent reason or motivation to believe one version of events over another. Research on this topic was stimulated by a paradigm pioneered by Wilkes and Leatherbarrow (1988) and H. M. Johnson and Seifert (1994). In it, people are presented with a fictitious report about an event unfolding over time. The report contains a target piece of information: For some readers, this target information is subsequently retracted, whereas for readers in a control condition, no correction occurs. Participants' understanding of the event is then assessed with a questionnaire, and the number of clear and uncontroverted references to the target (mis-)information in their responses is tallied.

A stimulus narrative commonly used in this paradigm involves a warehouse fire that is initially thought to have been caused by gas cylinders and oil paints that were negligently stored in a closet (e.g., Ecker, Lewandowsky, Swire, & Chang, 2011; H. M. Johnson & Seifert, 1994; Wilkes & Leatherbarrow, 1988). Some participants are then presented with a retraction, such as "the closet was actually empty." A comprehension test follows, and participants' number of references to the gas and paint in response to indirect inference questions about the event (e.g., "What caused the black smoke?") is counted. In addition, participants are asked to recall some basic facts about the event and to indicate whether they noticed any retraction.

Research using this paradigm has consistently found that retractions rarely, if ever, have the intended effect of eliminating reliance on misinformation, even when people believe, understand, and later remember the retraction (e.g., Ecker, Lewandowsky, & Apai, 2011; Ecker, Lewandowsky, Swire, & Chang, 2011; Ecker, Lewandowsky, & Tang, 2010; Fein, McCloskey, & Tomlinson, 1997; Gilbert, Krull, & Malone, 1990; Gilbert, Tafarodi, & Malone, 1993; H. M. Johnson & Seifert, 1994, 1998, 1999; Schul & Mazursky, 1990; van Oostendorp, 1996; van Oostendorp & Bonebakker, 1999; Wilkes & Leatherbarrow, 1988; Wilkes & Reynolds, 1999). In fact, a retraction will at most halve the number of references to misinformation, even when people acknowledge and demonstrably remember the retraction (Ecker, Lewandowsky, & Apai, 2011; Ecker, Lewandowsky, Swire, & Chang, 2011); in some studies, a retraction did not reduce reliance on misinformation at all (e.g., H. M. Johnson & Seifert, 1994).

When misinformation is presented through media sources, the remedy is the presentation of a correction, often in a temporally disjointed format (e.g., if an error appears in a newspaper, the correction will be printed in a subsequent edition). In laboratory studies, misinformation is often retracted immediately and within the same narrative (H. M. Johnson & Seifert, 1994). Despite this temporal and contextual proximity to the misinformation, retractions are ineffective. More recent studies (Seifert, 2002) have examined whether clarifying the correction (minimizing misunderstanding) might reduce the continued influence effect. In these studies, the correction was thus strengthened to include the phrase "paint and gas were never on the premises." Results showed that this enhanced negation of the presence of flammable materials backfired, making people even *more* likely to rely on the misinformation in their responses. Other additions to the correction were found to mitigate to a degree, but not eliminate, the continued influence effect: For example, when participants were given a rationale for how the misinformation originated, such as, "a truckers' strike prevented the expected delivery of the items," they were somewhat less likely to make references to it. Even so, the influence of the misinformation could still be detected. The wealth of studies on this phenomenon have documented its pervasive effects, showing that it is extremely difficult to return the beliefs of people who have been exposed to misinformation to a baseline similar to those of people who were never exposed to it.

Multiple explanations have been proposed for the continued influence effect. We summarize their key assumptions next.

Mental models

One explanation for the continued influence effect assumes that people build mental models of unfolding events (H. M. Johnson & Seifert, 1994; van Oostendorp & Bonebakker, 1999; Wilkes & Leatherbarrow, 1988). In this view, factor A (e.g., negligence) led to factor B (e.g., the improper storage of flammable materials), and factor B in conjunction with factor C (e.g., an electrical fault) caused outcome X (e.g., the fire) to happen. If a retraction invalidates a central piece of information (e.g., factor B, the presence of gas and paint), people will be left with a gap in their model of the event and an event representation that just "doesn't make sense" unless they maintain the false assertion. Therefore, when questioned about the event, a person may still rely on the retracted misinformation to respond (e.g., answering "The gas cylinders" when asked "What caused the explosions?"), despite demonstrating awareness of the correction when asked about it directly. Consistent with the mental-model notion, misinformation becomes particularly resilient to correction when people are asked to generate an explanation for why the misinformation might be true (Anderson, Lepper, & Ross, 1980). Moreover, the literature on false memory has shown that people tend to fill gaps in episodic memory with inaccurate but congruent information if such information is readily available from event schemata (Gerrie, Belcher, & Garry, 2006).

Nevertheless, the continued use of discredited mental models despite explicit correction remains poorly understood. On the one hand, people may be uncomfortable with gaps in their knowledge of an event and hence prefer an incorrect model over an incomplete model (Ecker, Lewandowsky, & Apai, 2011; Ecker et al., 2010; H. M. Johnson & Seifert, 1994; van Oostendorp & Bonebakker, 1999). The conflict created by having a plausible answer to a question readily available, but at the same time knowing that it is wrong, may be most easily resolved by sticking to the original idea and ignoring the retraction.

Retrieval failure

Another explanation for the continued influence of misinformation is the failure of controlled memory processes. First, misinformation effects could be based on source confusion or misattribution (M. K. Johnson, Hashtroudi, & Lindsay, 1993). People may correctly recollect a specific detail—in the case of the story of the fire discussed earlier, they may remember that it was assumed the fire was caused by oil and paints—but incorrectly attribute this information to the wrong source. For example, people could falsely recollect that this information was contained in the final police report rather than an initial report that was subsequently retracted.

Second, misinformation effects could be due to a failure of strategic monitoring processes (Moscovitch & Melo, 1997). Ayers and Reder (1998) have argued that both valid and invalid memory entries compete for automatic activation, but that contextual integration requires strategic processing. In other words, it is reasonable to assume that a piece of misinformation that supplies a plausible account of an event will be activated when a person is questioned about the event. A strategic monitoring process is then required to determine the validity of this automatically retrieved piece of information. This may be the same monitoring process involved in source attribution, whereby people decide whether a memory is valid and put into the correct encoding context, or whether it was received from a reliable source (Henkel & Mattson, 2011).

Third, there is some evidence that processing retractions can be likened to attaching a "negation tag" to a memory entry (e.g., "there were oil paints and gas cylinders—NOT"; Gilbert et al., 1990; H. M. Johnson & Seifert, 1998). H. M. Johnson and Seifert (1998) showed that the automatic activation of misinformation in memory continues whenever it is referred to, even after a clear correction. For example, after reading, "John played hockey for New York. Actually, he played for Boston," reading "the team" results in the activation of both cities in memory. The negation tag on the information can be lost, especially when strategic memory processing is impaired, as it can be in old age (E. A. Wilson & Park, 2008) or under high cognitive load (Gilbert et al., 1990). From this perspective, negations should be more successful when they can be encoded as an affirmation of an alternative attribute (Mayo, Schul, & Burnstein, 2004). Mayo and her colleagues (2004) found support for this possibility in the domain of person perception. For example, the information that Jim is "not messy" allows an affirmative encoding, "Jim is tidy," incorporating the polar opposite of "messy"; in contrast, learning that Jim is "not charismatic" does not offer an alternative encoding because of the unipolar nature of the trait "charismatic." Accordingly, Mayo et al. found that people were more likely to misremember unipolar traits (e.g., remembering "not charismatic" as "charismatic") than bipolar traits (e.g., "not messy" was rarely misremembered as "messy," presumably because "not messy" was recoded as "tidy" during encoding).

Fluency and familiarity

Whereas the preceding accounts focus on whether people are more likely to recall a piece of misinformation or its correction, a *fluency* approach focuses on the experience of processing the two types of information upon later reexposure (Schwarz et al., 2007). Without direct questions about truth values, people may rely on their metacognitive experience of fluency during thinking about an event to assess plausibility of their thoughts, a process that would give well-formed, coherent models an advantage—as long as thoughts flow smoothly, people may see little reason to question their veracity (Schwarz et al., 2007). From this perspective, misinformation can exert an influence by increasing the perceived familiarity and coherence of related material encountered later in time. As a result, retractions may fail, or even backfire (i.e., by entrenching the initial misinformation), if they directly or indirectly repeat false information in order to correct it, thus further enhancing its familiarity.

For example, correcting an earlier account by explaining that there were *no* oil paints and gas cylinders present requires the repetition of the idea that "paints and gas were present." Generally, repetition of information strengthens that information in memory and thus strengthens belief in it, simply because the repeated information seems more familiar or is associated with different contexts that can serve as later retrieval cues (Allport & Lepkin, 1945; Eakin, Schreiber, & Sergent-Marshall, 2003; Ecker, Lewandowsky, Swire, & Chang, 2011; Henkel & Mattson, 2011; Mitchell & Zaragoza, 1996; Schul & Mazursky, 1990; Verkoeijen, Rikers, & Schmidt, 2004; Zaragoza & Mitchell, 1996). It follows that when people later reencounter the misinformation (e.g., "oil paints and gas cylinders were present"), it may be more familiar to them than it would have been without the retraction, leading them to think, "I've heard that before, so there's probably something to it." This impairs the effectiveness of public-information campaigns intended to correct misinformation (Schwarz et al., 2007).

A common format for such campaigns is a "myth versus fact" approach that juxtaposes a given piece of false information with a pertinent fact. For example, the U.S. Centers for Disease Control and Prevention offer patient handouts that counter an erroneous health-related belief (e.g., "The side effects of flu vaccination are worse than the flu") with relevant facts (e.g., "Side effects of flu vaccination are rare and mild"). When recipients are tested immediately after reading such hand-outs, they correctly distinguish between myths and facts, and report behavioral intentions that are consistent with the information provided (e.g., an intention to get vaccinated). However, a short delay is sufficient to reverse this effect: After a mere 30 minutes, readers of the handouts identify more "myths" as "facts" than do people who never received a handout to begin with (Schwarz et al., 2007). Moreover, people's behavioral intentions are consistent with this confusion: They report fewer vaccination intentions than people who were not exposed to the handout.

Because recollective memory shows more age-related impairment than familiarity-based memory does (Jacoby, 1999), older adults (and potentially children) are particularly vulnerable to these backfire effects because they are more likely to forget the details of a retraction and retain only a sense of familiarity about it (Bastin & Van Der Linden, 2005;

Holliday, 2003; Jacoby, 1999). Hence, they are more likely to accept a statement as true after exposure to explicit messages that it is false (Skurnik, Yoon, Park, & Schwarz, 2005; E. A. Wilson & Park, 2008).

A similar effect has recently been reported in the very different field of corporate-event sponsorship. Whereas some companies spend large amounts of money to be officially associated with a certain event, such as the Olympic Games, other companies try to create the impression of official affiliation without any sponsorship (and hence without expenditure on their part), a strategy known as "ambushing." Not only is this strategy successful in associating a brand with an event, but attempts to publically expose a company's ambushing attempt (i.e., "counter-ambushing") may lead people to remember the feigned brand-to-event association even better (Humphreys et al., 2010).

Reactance

Finally, retractions can be ineffective because of social reactance (Brehm & Brehm, 1981). People generally do not like to be told what to think and how to act, so they may reject particularly authoritative retractions. For this reason, misinformation effects have received considerable research attention in a courtroom setting where mock jurors are presented with a piece of evidence that is later ruled inadmissible. When the jurors are asked to disregard the tainted evidence, their conviction rates are *higher* when an "inadmissible" ruling was accompanied by a judge's extensive legal explanations than when the inadmissibility was left unexplained (Pickel, 1995, Wolf & Montgomery, 1977). (For a review of the literature on how jurors process inadmissible evidence, see Lieberman & Arndt, 2000.)

Reducing the Impact of Misinformation

So far, we have shown that simply retracting a piece of information will not stop its influence. A number of other techniques for enhancing the effectiveness of retractions have been explored, but many have proven unsuccessful. Examples include enhancing the clarity of the retraction (Seifert, 2002; van Oostendorp, 1996) and presenting the retraction immediately after the misinformation to prevent inferences based on it before correction occurs (H. M. Johnson & Seifert, 1994; Wilkes & Reynolds, 1999).

To date, only three factors have been identified that can increase the effectiveness of retractions: (a) warnings at the time of the initial exposure to misinformation, (b) repetition of the retraction, and (c) corrections that tell an alternative story that fills the coherence gap otherwise left by the retraction.

Preexposure warnings

Misinformation effects can be reduced if people are explicitly warned up front that information they are about to be given may be misleading (Chambers & Zaragoza, 2001; Ecker et al., 2010; Jou & Foreman, 2007; Schul, 1993). Ecker et al. (2010) found, however, that to be effective, such warnings need to specifically explain the ongoing effects of misinformation rather than just generally mention that misinformation may be present (as in Marsh & Fazio, 2006). This result has obvious application: In any situation in which people are likely to encounter misinformation—for example, in advertising, in fiction that incorporates historical or pseudoscientific information, or in court settings, where jurors often hear information they are later asked to disregard—warnings could be given routinely to help reduce reliance on misinformation.

Warnings seem to be more effective when they are administered before the misinformation is encoded rather than after (Chambers & Zaragoza, 2001; Ecker et al., 2010; Schul, 1993). This can be understood in terms of Gricean maxims about communication (Grice, 1975): People by default expect the information presented to be valid, but an a priori warning can change that expectation. Such a warning would allow recipients to monitor the encoded input and "tag" it as suspect. Consistent with this notion, Schul (1993) found that people took longer to process misinformation when they had been warned about it, which suggests that, rather than quickly dismissing false information, people took care to consider the misinformation within an alternative mental model. Warnings may induce a temporary state of skepticism, which may maximize people's ability to discriminate between true and false information. Later in this article, we return to the issue of skepticism and show how it can facilitate the detection of misinformation.

The fact that warnings are still somewhat effective *after* misinformation is encoded supports a dual-process view of misinformation retrieval, which assumes that a strategic monitoring process can be used to assess the validity of automatically retrieved pieces of misinformation (Ecker et al., 2010). Because this monitoring requires effort and cognitive resources, warnings may be effective in prompting recipients of information to be vigilant.

Repeated retractions

The success of retractions can also be enhanced if they are repeated or otherwise strengthened. Ecker, Lewandowsky, Swire, and Chang (2011) found that if misinformation was encoded repeatedly, repeating the retraction helped alleviate (but did not eliminate) misinformation effects. However, misinformation that was encoded only once persisted to the same extent whether one retraction or three retractions were given. This means that even after only weak encoding, misinformation effects are extremely hard to eliminate or drive below a certain level of irreducible persistence, irrespective of the strength of subsequent retractions.

There are a number of reasons why this could be the case. First, some misinformation effects may arise from automatic processing, which can be counteracted by strategic control processes only to the extent that people are aware of the automatic influence of misinformation on their reasoning (cf. T. D. Wilson & Brekke, 1994). Second, inferences based on misinformation may rely on a sample of the memory representations of that misinformation, and each of these representations may be offset (thereby having its impact reduced, but not eliminated) by only one retraction. Once a memory token has been associated with a "retracted" marker, further retractions do not appear to strengthen that marker; therefore, repeated retractions do not further reduce reliance on weakly encoded misinformation because weak encoding means only a single representation is created, whereas the multiple representations that arise with strong encoding can benefit from strong (i.e., multiple) retractions. (For a computational implementation of this sampling model, see Ecker, Lewandowsky, Swire, & Chang, 2011.) Finally, the repetition of corrections may ironically decrease their effectiveness. On the one hand, some evidence suggests a "protest-too-much" effect, whereby overexerting a correction may reduce confidence in its veracity (Bush, Johnson, & Seifert, 1994). On the other hand, as noted above, corrections may paradoxically enhance the impact of misinformation by repeating it in retractions (e.g., Schwarz et al., 2007).

Whatever the underlying cognitive mechanism, the findings of Ecker, Lewandowsky, Swire, & Chang, (2011) suggest that the repetition of initial misinformation has a stronger and more reliable (negative) effect on subsequent inferences than the repetition of its retraction does. This asymmetry in repetition effects is particularly unfortunate in the domain of social networking media, which allow information to be disseminated quickly, widely, and without much fact-checking, and to be taken only from sources consonant with particular worldviews.

Filling the gap: Providing an alternative narrative

We noted earlier that retractions can cause a coherence gap in the recipient's understanding of an event. Given that internal coherence plays a key role in truth assessments (Johnson-Laird, 2012; Pennington & Hastie, 1993), the resulting gap may motivate reliance on misinformation in spite of a retraction (e.g., "It wasn't the oil and gas, but what else could it be?"). Providing an alternative causal explanation of the event can fill the gap left behind by retracting misinformation. Studies have shown that the continued influence of misinformation can be eliminated through the provision of an alternative account that explains *why* the information was incorrect (e.g., "There were no gas cylinders and oil paints, but arson materials have been found"; "The initial suspect may not be guilty, as there is an alternative suspect"; H. M. Johnson & Seifert, 1994; Tenney, Cleary, & Spellman, 2009).

To successfully replace the misinformation, the alternative explanation provided by the correction must be plausible, account for the important causal qualities in the initial report, and, ideally, explain why the misinformation was thought to be correct in the first place (e.g., Rapp & Kendeou, 2007; Schul & Mazursky, 1990; Seifert, 2002). For example, noting that the suspected WMD sites in Iraq were actually grain silos would not explain why the initial report that they housed WMDs occurred, so this alternative might be ineffective. An alternative will be more compelling if it covers the causal bases of the initial report. For example, an account might state that a suspected WMD site was actually a chemical factory, which would be more plausible because a chemical factory—unlike a grain silo—may contain components that also occur in WMDs (cf. H. M. Johnson & Seifert, 1994). A correction may also be more likely to be accepted if it accounts for why the initial incorrect information was offered—for example, by stating that WMDs *had* been present in Iraq, but were destroyed before 2003.

Corrections can be particularly successful if they explain the motivation behind an incorrect report. For example, one might argue that the initial reports of WMDs facilitated the U.S. government's intention to invade Iraq, so the misinformation was offered without sufficient evidence (i.e., government officials were "trigger-happy"; cf. Lewandowsky, Stritzke, Oberauer, & Morales, 2005, 2009). Drawing attention to a source's motivation can undermine the impact of misinformation. For example, Governor Ronald Reagan defused President Jimmy Carter's attack on his Medicare policies in a 1980 U.S. presidential debate by stating, "There you go again!"; by framing information as what would be "expected" from its source, Reagan discredited it (Cialdini, 2001).

Some boundary conditions apply to the alternative-account technique. The mere mention, or self-generation, of alternative ideas is insufficient to reduce reliance on misinformation (H. M. Johnson & Seifert, 1994, 1999; Seifert, 2002). That is, the alternative must be integrated into the existing information from the same source.

Also, people generally prefer simple explanations over complex explanations (Chater & Vitanyi, 2003; Lombrozo, 2006, 2007). When misinformation is corrected with an alternative, but much more complex, explanation, people may reject it in favor of a simpler account that maintains the misinformation. Hence, providing too many counterarguments, or asking people to generate many counterarguments, can potentially backfire (Sanna, Schwarz, & Stocker, 2002; Schwarz et al., 2007). This "overkill" backfire effect can be avoided by asking people to generate only a few arguments regarding why their belief may be wrong; in this case, the self-generation of the counterarguments can assist debiasing (Sanna & Schwarz, 2006). Moreover, suspicion about the rationale behind the correction, as well as for the rationale behind the initial presentation of the misinformation, may be particularly important in the case of corrections of political misinformation. Specific motivations likely underlie politicians' explanations for events, so people may place more suspicion on alternative explanations from these sources.

In summary, the continued influence of misinformation can be reduced with three established techniques: (a) People can be warned about the potentially misleading nature of forthcoming information before it is presented; (b) corrections can be repeated to strengthen their efficacy; and (c) corrections can be accompanied by alternative explanations for the event in question, thus preventing causal gaps in the account. The last technique is particularly effective; however, it is not always possible, because an alternative explanation may not be available when an initial report is found to be in error. In addition, further complications arise when corrections of misinformation challenge the recipients' worldview more broadly, as we discuss in the following section.

Corrections in the Face of Existing Belief Systems: Worldview and Skepticism

Recipients' individual characteristics play an important role in determining whether misinformation continues to exert an influence. Here, we address two such characteristics—namely, worldview and level of skepticism—that exert opposing effects on the efficacy of corrections.

Worldview

Given that people more readily accept statements that are consistent with their beliefs, it is not surprising that people's worldview, or personal ideology, plays a key role in the persistence of misinformation. For example, Republicans are more likely than Democrats to continue to believe the "birthers" and to accept claims about the presence of WMDs in Iraq despite retractions (Kull et al., 2003; Travis, 2010). At the opposite end of the political spectrum, liberals are less accurate than conservatives when it comes to judging the consequences of higher oil prices. In particular, whereas experts foresee considerable future risks to human health and society arising from "peak oil" (Schwartz, Parker, Hess, & Frumkin, 2011), surveys have shown that liberals are less likely than conservatives to recognize the magnitude of these risks (Nisbet, Maibach, & Leiserowitz, 2011).[2]

From this real-world survey research, we know that people's preexisting attitudes often determine their level of belief in misinformation after it has been retracted. What is less well understood is whether retractions (a) fail to reduce reliance on misinformation specifically among people for whom the retraction violates personal belief or (b) are equally effective for all people, with observed post-retraction differences in belief only mirroring pre-retraction differences. Both possibilities are consistent with the literature on truth assessments discussed earlier. Compared with worldview-congruent retractions, retractions that contradict one's worldview are inconsistent with other beliefs, less familiar, more difficult to process, less coherent, less supported in one's social network, and more likely to be viewed as coming from an untrustworthy source. All of these factors may undermine the apparent truth value of a retraction that challenges one's belief system. Conversely, misinformation consistent with one's worldview fits with other beliefs, and is therefore more familiar, easier to process, more coherent, more supported in one's network, and more likely to be viewed as coming from a trusted source. Accordingly, worldview-based differences in the effectiveness of retractions may reflect the differential appeal of the misinformation, the retraction, or both. The evidence concerning these distinctions is sparse and mixed.

In one study, people with high and low levels of racial prejudice were presented with a narrative about a robbery involving an indigenous Australian who was either the suspect of a crime (in one experiment) or a hero who prevented the crime (in another experiment; Ecker, Lewandowsky, Fenton, & Martin, 2012). People's references to the racial information covaried with their racial attitudes; that is, people who were prejudiced mentioned the indigenous suspect more often and the indigenous hero less often. However, this effect was found irrespective of whether a retraction had been offered, indicating that the retraction was equally effective for low- and high-prejudice participants. Similarly, in a study in which a fictitious plane crash was initially attributed to a terrorist bomb before participants received a correction clarifying that a later investigation revealed a faulty fuel tank as the cause, participants with high levels of Islamophobia mentioned terrorism-related material more often on a subsequent inference test than their counterparts who scored lower on Islamophobia did, although a retraction was equally effective for both groups (unpublished analysis of Ecker, Lewandowsky, & Apai, 2011).

In contrast to these findings, reports from other studies have indicated that worldviews affect how people process corrective messages. In one study, retractions of nonfictitious misperceptions (e.g., the mistaken belief that President Bush's tax cuts in the early 2000s had increased revenues; the idea that there were WMDs in Iraq) were effective only among people whose political orientation was supported by the retraction (Nyhan & Reifler, 2010). When the corrections were worldview-dissonant (in this case, for Republican participants), a "backfire" effect was observed, such that participants became *more* committed to the misinformation. Hart and Nisbet (2011) reported a similar backfire effect using stimuli related to climate change. In their study, people were presented with messages highlighting the adverse effects on health caused by climate change. Compared with a control group, Democrats who received these messages were found to increase their support for climate mitigation policies, whereas support declined among Republicans.

The sway that people's worldview holds over their perceptions and cognitions can be illustrated through a consideration of some other instances of polarization. Gollust, Lantz, and Ubel (2009) showed that even public-health messages can have a polarizing effect along party lines: When people were presented with evidence that Type 2 diabetes can be caused by social circumstances (e.g., a scarcity of healthy food combined with an abundance of junk food in poor neighborhoods), subsequent endorsement of potential policy options (e.g., banning fast-food concessions in public schools) was found to decline among Republicans but to increase among Democrats in comparison with a control group that did not receive any information about the causes of diabetes. Berinsky (2012) reported similar polarizing effects in experiments in which the death-panel myth surrounding President Obama's health plan was rebutted.

The role of personal worldview may not be limited to the effects of misinformation regarding political issues: When people who felt a high degree of connection with their favorite brand were provided with negative information about the brand, they reported reduced self-esteem but retained their positive brand image, whereas the self-esteem of those with a low degree of personal connection to brands remained unchanged (Cheng, White, & Chaplin, 2011).

What boundary conditions limit the influence of one's worldview on one's acceptance of corrections? The study by Ecker, Lewandowsky, Fenton, and Martin (2012) involved fictitious events that contained attitude-relevant information, whereas the studies just discussed involved real-world events and politicians about which people likely had preexisting opinions (Nyhan & Reifler, 2010). We therefore suggest that worldview affects the effectiveness of a retraction when the misinformation concerns a real-world event that relates to preexisting beliefs (e.g., it is harder to accept that the report of WMDs in Iraq was false if one supported the 2003 invasion). In confirmation of this idea, the political-science literature contains reports of people being sensitive to factual or corrective information on issues that arguably lack salience and emotiveness (Barabas & Jerit, 2009; Blais et al., 2010; Gaines, Kuklinski, Quirk, Peyton, & Verkuilen, 2007; for a review of that literature, see Nyhan & Reifler, 2012). These findings suggest that not all political issues necessarily lead to polarization.

Making things worse: Backfire effects

From a societal view, misinformation is particularly damaging if it concerns complex real-world issues, such as climate change, tax policies, or the decision to go to war. The preceding discussion suggests that in such real-world scenarios, people will refer more to misinformation that is in line with their attitudes *and* will be relatively immune to corrections, such that retractions may even backfire and strengthen the initially held beliefs (Nyhan & Reifler, 2010). This backfire effect has been attributed to a process by which people implicitly counterargue against any information that challenges their worldview. Prasad et al. (2009) illuminated this counterarguing process particularly strikingly by using a "challenge interview" technique, asking participants to respond aloud to information that debunked their preexisting beliefs. Participants either came up with counterarguments or simply remained unmovable (e.g., as illustrated by responses like "I guess we still can have our opinions and feel that way even though they say that"). These findings mesh well with the work on "motivated skepticism" by Taber and Lodge (2006), which has shown similar responses to challenges to political opinions (as opposed to facts). In their study, people uncritically accepted arguments for their own position but were highly skeptical of opposing arguments, and they actively used counterarguments to deride or invalidate worldview-incongruent information (as revealed through protocol analysis).

Such backfire effects, also known as "boomerang" effects, are not limited to the correction of misinformation but also affect other types of communication. For example, messages intended to promote positive health behaviors can backfire, such that campaigns to reduce smoking may ironically lead to an increase in smoking rates (for a review, see Byrne & Hart, 2009). In other areas of research, backfire effects have been linked to people not only rejecting the message at hand but also becoming predisposed to reject any future messages from its source (Brehm & Brehm, 1981). If generalizations of source distrust may occur in the context of corrections of misinformation, their potential existence is cause for concern.

A phenomenon that is closely related to the backfire effects arising with worldview-dissonant corrections involves *belief polarization*. Belief polarization is said to occur if presentation of the same information elicits further attitudinal divergence between people with opposing views on an issue (Lord, Ross, & Lepper, 1979). For example, when both religious believers and nonbelievers were exposed to a fictitious report disproving the Biblical account of the resurrection, belief increased among believers, whereas nonbelievers became more skeptical (Batson, 1975). This increased belief among believers is isomorphic to the worldview backfire effect in response to corrective information.

In another example, supporters and opponents of nuclear power reacted in opposite fashion to identical descriptions of technological breakdowns at a nuclear plant: Whereas supporters focused on the fact that the safeguards worked to prevent the accident from being worse, opponents focused on the fact that the breakdown occurred in the first place (Plous, 1991). Not unexpectedly, techniques for reducing belief polarization are highly similar to techniques for overcoming worldview-related resistance to corrections of misinformation.

Feelings of affiliation with a source also influence whether or not one accepts a piece of information at face value. For example, Berinsky (2012) found that among Republicans, corrections of the death-panel myth were effective primarily when they were issued by a Republican politician. However, judgments of a source's credibility are themselves a function of beliefs: If you believe a statement, you judge its source to be more credible (Fragale & Heath, 2004). This interaction between belief and credibility judgments can lead to an epistemic circularity, whereby no opposing information is ever judged sufficiently credible to overturn dearly held prior knowledge. For example, Munro (2010) has shown that exposure to belief-threatening scientific evidence can lead people to discount the scientific method itself: People would rather believe that an issue cannot be resolved scientifically, thus discounting the evidence, than accept scientific evidence in opposition to their beliefs. Indeed, even high levels of education do not protect against the worldview-based rejection of information; for example, Hamilton (2011) showed that a higher level of education made Democrats more likely to view global warming as a threat, whereas the reverse was true for Republicans. This constitutes an extreme case of belief polarization (see also Malka, Krosnick, & Langer, 2009; McCright & Dunlap, 2011). Similarly, among Republicans, greater education was associated with a greater increase in the belief that President Obama was a Muslim (he is not) between 2009 and 2010 (Sides, 2010). Among Democrats, few held this mistaken belief, and education did not moderate the effect.

In summary, personal beliefs can facilitate the acquisition of attitude-consonant misinformation, increase reliance on misinformation, and inoculate against the correction of false beliefs (Ecker et al., 2012; Kull et al., 2003; Lewandowsky et al., 2005, 2009; Nyhan & Reifler, 2010; Pedersen, Clarke, Dudgeon, & Griffiths, 2005; Pedersen, Attwell, & Heveli, 2007). Interestingly, the extent to which material is emotive does not appear to affect its persistence in memory after correction (Ecker, Lewandowsky, & Apai, 2011). For example, after a retraction of a report about the cause of a plane crash, people will mistakenly continue to refer to a "terrorist attack" as the cause just as often as "bad weather" or a "technical fault," even when they are demonstrably more emotionally affected by the first. Thus, people do not simply cling to the most emotional version of an event. Although information that challenges people's worldview is likely to elicit an emotive response, emotion by itself is not sufficient to alter people's resistance to corrections.

One limitation of this conclusion is that worldview does not by itself serve as a process explanation. Although it is indubitably useful to be able to predict a person's response to corrections on the basis of party affiliation or other indicators of worldview, it would be helpful if the cognitive processes underlying that link could be characterized in greater detail. Recent advances in illuminating those links have been promising (e.g., Castelli & Carraro, 2011; Carraro, Castelli, & Macchiella, 2011; Jost, Glaser, Kruglanski, & Sulloway, 2003b). It is possible that one's worldview forms a frame of reference for determining, in Piaget's (1928) terms, whether to assimilate information or to accommodate it. If one's investment in a consistent worldview is strong, changing that worldview to accommodate inconsistencies may be too costly or effortful. In a sense, the worldview may serve as a schema for processing related information (Bartlett, 1977/1932), such that relevant factual information may be discarded or misinformation preserved.

Taming worldview by affirming it

The research on preexisting attitudes and worldviews implies that debiasing messages and retractions must be tailored to their specific audience, preferably by ensuring that the correction is consonant with the audience's worldview. For example, the work on "cultural cognition" by Kahan and colleagues (e.g., Kahan, 2010) have repeatedly shown that framing solutions to a problem in worldview-consonant terms can enhance acceptance of information that would be rejected if it were differently framed. Thus, people who might oppose nanotechnology because they have an "eco-centric" outlook may be less likely to dismiss evidence of its safety if the use of nanotechnology is presented as part of an effort to protect the environment. Similarly, people who oppose climate science because it challenges their worldview may do so less if the response to climate change is presented as a business opportunity for the nuclear industry (cf. Feygina, Jost, & Goldsmith, 2010). Even simple changes in wording can make information more acceptable by rendering it less threatening to a person's worldview. For example, Republicans are far more likely to accept an otherwise identical charge as a "carbon offset" than as a "tax," whereas the wording has little effect on Democrats or Independents (whose values are not challenged by the word "tax"; Hardisty, Johnson, & Weber, 2010).

Another way in which worldview-threatening messages can be made more palatable involves coupling them with self-affirmation—that is, by giving recipients an opportunity to affirm their basic values as part of the correction process (Cohen et al., 2007, Nyhan & Reifler, 2011). Self-affirmation can be achieved by asking people to write a few sentences about a time they felt especially good about themselves because they acted on a value that was important to them. Compared with people who received no affirmation, those who self-affirmed became more receptive to messages that otherwise might have threatened their worldviews. Self-affirmation may give the facts a fighting chance (Cohen et al., 2007, Nyhan & Reifler, 2011) by helping people handle challenges to their worldviews. Intriguingly, self-affirmation also enables people who have a high personal connection to a favorite brand to process negative information about it appropriately (by lowering their evaluations of the brand rather than their own self-esteem; Cheng et al., 2011).

Factors that assist people in handling inconsistencies in their personal perspectives may also help to promote acceptance of corrections. For example, distancing oneself from a self-focused perspective has been shown to promote wise reasoning (Kross & Grossmann, 2012) and may be helpful in processing corrections.

Skepticism: A key to accuracy

We have reviewed how worldview and prior beliefs can exert a distorting influence on information processing. However, some attitudes can also safeguard against misinformation effects. In particular, *skepticism* can reduce susceptibility to misinformation effects if it prompts people to question the origins of information that may later turn out to be false. For example, people who questioned the official casus belli for the invasion of Iraq (destroying WMDs) have been shown to be more accurate in processing war-related information in general (Lewandowsky et al., 2005). Suspicion or skepticism about the overall context (i.e., the reasons for the war) thus led to more accurate processing of specific information about the event in question. Importantly, in this instance, skepticism also ensured that correct information was recognized more accurately, and thus did not translate into cynicism or a blanket denial of *all* war-related information. In a courtroom setting, Fein et al. (1997) showed that mock jurors who were asked to disregard a piece of inadmissible evidence were still influenced by the retracted evidence despite claiming they were not—unless they were made suspicious of the motives of the prosecutor who had introduced the evidence.

These findings mesh well with related research on trust. Although trust plays a fundamental role in most human relationships, and the presence of distrust is often corrosive (e.g., Whyte & Crease, 2010), there are situations in which distrust can have a positive function. For example, Schul et al. (2008) showed that when they elicited distrust in participants by showing them a face that had been rated as "untrustworthy" by others, the participants were more likely to be able to solve nonroutine problems on a subsequent, completely unrelated task. By contrast, participants in whom trust was elicited performed much better on routine problems (but not nonroutine problems), a result suggesting that distrust causes people to explore their environment more carefully, which sensitizes them to the existence of nonroutine contingencies. Similarly, Mayer and Mussweiler (2011) showed that priming people to be distrustful enhances their creativity in certain circumstances.

Taken together, these results suggest that a healthy sense of skepticism or induced distrust can go a long way in avoiding the traps of misinformation. These benefits seem to arise from the nonroutine, "lateral" information processing that is primed when people are skeptical or distrustful (Mayer & Mussweiler, 2011; Schul et al., 2008). However, distrust and skepticism are most likely to exert an influence when they are experienced at the time of message exposure, and they do not always protect people from unreliable or intentionally misleading sources, particularly when a source's motivation becomes apparent only after message encoding. Even when misinformation is identified as intentionally deceptive (as opposed to accidentally wrong) or as stemming from an unreliable source, its effects can prevail (Green & Donahue, 2011; Henkel & Mattson, 2011). For example, Green and Donahue (2011) first presented people with a report that was found to change people's attitudes about an issue (e.g., a report about a heroin-addicted child changed people's attitudes toward the effectiveness of social youth-assistance programs). Participants then received a retraction stating that the report was inaccurate, either because of a mix-up (error condition) or because the author had made up most of the "facts" in order to sensationalize the report (deception condition). The results showed that participants were motivated to undo their attitudinal changes, especially in the deception condition, but that the effects of misinformation could not be undone in either condition. The misinformation had a continuing effect on participants' attitudes even after a retraction established the author had made it up.

Using misinformation to inform

Unlike brief interventions using the "myth-versus-fact" approach (Schwarz et al., 2007), whose adverse implications we discussed earlier, it appears that a careful and prolonged dissection of incorrect arguments may facilitate the acquisition of correct information. To illustrate this point, Kowalski and Taylor (2009) conducted a naturalistic experiment in which they compared a standard teaching format with an alternative approach in which lectures explicitly refuted 17 common misconceptions about psychology but left others unchallenged. The results showed that direct refutation was more successful in reducing misconceptions than was the nonrefutational provision of the same information. On the basis of a more extensive review of the literature, Osborne (2010) likewise argued for the centrality of argumentation and rebuttal in science education, suggesting that classroom studies "show improvements in conceptual learning when students engage in argumentation" (p. 464).

Recent work has indicated that argumentation and engagement with an opponent can even work in the political arena (Jerit, 2008). Jerit's analysis of more than 40 opinion polls ran contrary to the conventional wisdom that to win a policy debate, political actors should selectively highlight issues that mobilize public opinion in favor of their position and not engage an opponent in dialogue. Taking the argumentation and refutation approach to an extreme, some have suggested that even explicit misinformation can be used as an effective teaching tool. Bedford (2010) reported a case study in which students learned about climate science by studying "denialist" literature—that is, they acquired actual knowledge by analyzing material that contained misinformation in depth and by developing the skills required to detect the flaws in the material. In line with Osborne's (2010) review, an in-depth discussion of misinformation and its correction may assist people in working through inconsistencies in their understanding and promote the acceptance of corrections.

Debiasing in an Open Society

Knowledge about the processes underlying the persistence of misinformation and about how misinformation effects can be avoided or reduced is of obvious public interest. Today, information is circulated at a faster pace and in greater amounts than ever before in society, and demonstrably false beliefs continue to find traction in sizable segments of the populace. The development of workable debiasing and retraction techniques, such as those reviewed here, is thus of considerable practical importance.

Encouraging precedents for the effectiveness of using such techniques on a large scale have been reported in Rwanda (e.g., Paluck, 2009), where a controlled, yearlong field experiment revealed that a radio soap opera built around messages of reducing intergroup prejudice, violence, and survivors' trauma altered listeners' perceptions of social norms and their behavior—albeit not their beliefs—in comparison with a control group exposed to a health-focused soap opera. This field study confirmed that large-scale change *can* be achieved using conventional media. (Paluck's experiment involved delivery of the program via tape recorders, but this was for reasons of experimental control and convenience, and it closely mimicked the way in which radio programs are traditionally consumed by Rwandans.)

Concise recommendations for practitioners

The literature we have reviewed thus far may appear kaleidoscopic in its complexity. Indeed, a full assessment of the debiasing literature must consider numerous nuances and subtleties, which we aimed to cover in the preceding sections. However, it is nonetheless possible to condense the core existing knowledge about debiasing into a limited set of recommendations that can be of use to practitioners.[3]

We summarize the main points from the literature in Figure 1 and in the following list of recommendations:

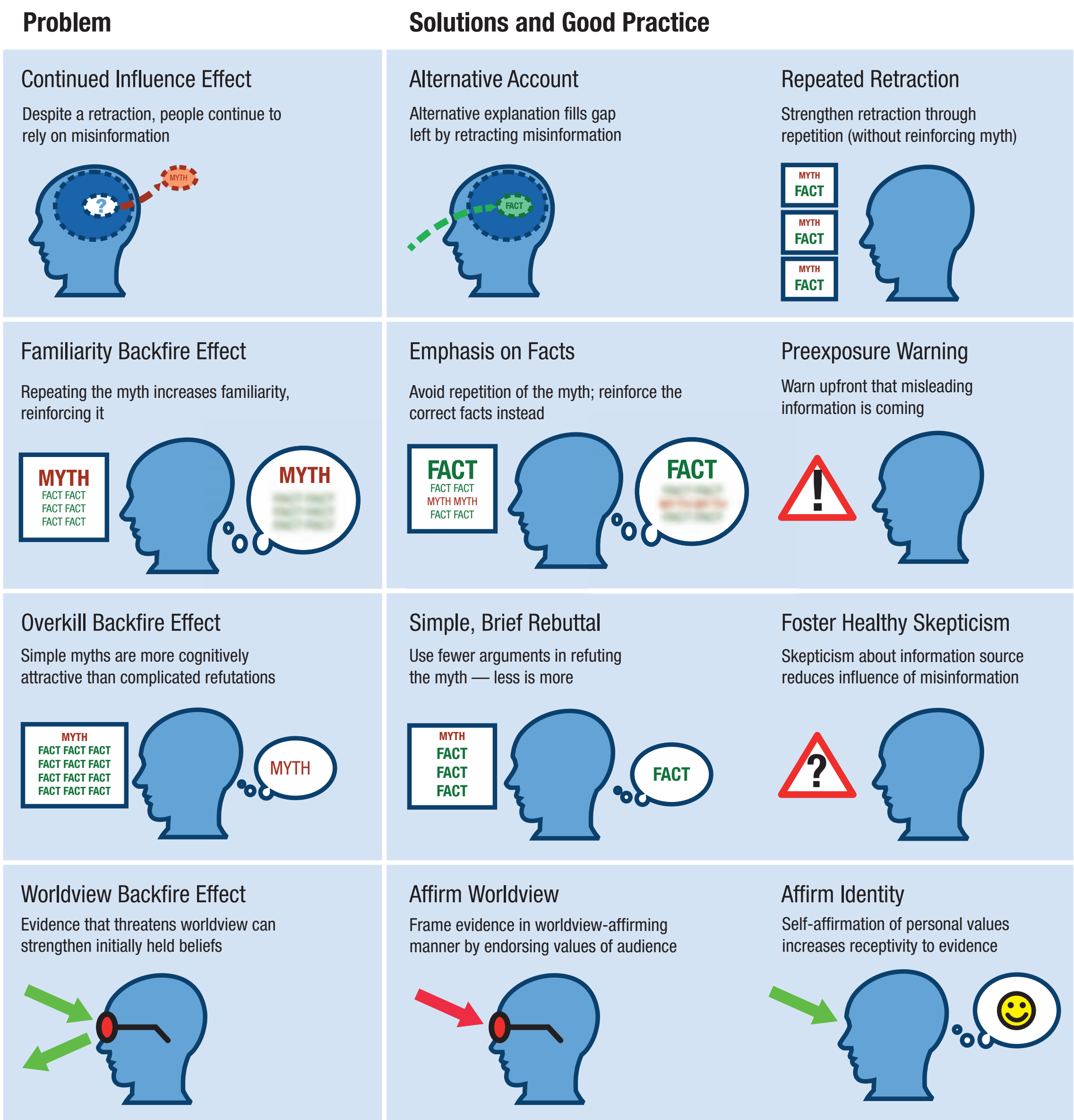

Fig. 1. A graphical summary of findings from the misinformation literature relevant to communication practitioners. The left-hand column summarizes the cognitive problems associated with misinformation, and the right-hand column summarizes the solutions reviewed in this article.

- Consider what gaps in people's mental event models are created by debunking and fill them using an alternative explanation.
- Use repeated retractions to reduce the influence of misinformation, but note that the risk of a backfire effect increases when the original misinformation is repeated in retractions and thereby rendered more familiar.
- To avoid making people more familiar with misinformation (and thus risking a familiarity backfire effect), emphasize the facts you wish to communicate rather than the myth.
- Provide an explicit warning before mentioning a myth, to ensure that people are cognitively on guard and less likely to be influenced by the misinformation.
- Ensure that your material is simple and brief. Use clear language and graphs where appropriate. If the myth is simpler and more compelling than your debunking, it will be cognitively more attractive, and you will risk an overkill backfire effect.
- Consider whether your content may be threatening to the worldview and values of your audience. If so, you risk a worldview backfire effect, which is strongest among those with firmly held beliefs. The most receptive people will be those who are not strongly fixed in their views.
- If you must present evidence that is threatening to the audience's worldview, you may be able to reduce the worldview backfire effect by presenting your content in a worldview-affirming manner (e.g., by focusing on opportunities and potential benefits rather than risks and threats) and/or by encouraging self-affirmation.
- You can also circumvent the role of the audience's worldview by focusing on behavioral techniques, such as the design of choice architectures, rather than overt debiasing.

Future Directions

Our survey of the literature has enabled us to provide a range of recommendations and draw some reasonably strong conclusions. However, our survey has also identified a range of issues about which relatively little is known, and which deserve future research attention. We wish to highlight three such issues in particular—namely, the roles played by emotion, individual differences (e.g., race or culture), and social networks in misinformation effects.

Concerning emotion, we have discussed how misinformation effects arise independently of the emotiveness of the information (Ecker, Lewandowsky, & Apai, 2011). But we have also noted that the likelihood that people will pass on information is based strongly on the likelihood of its eliciting an emotional response in the recipient, rather than its truth value (e.g., K. Peters et al., 2009), which means that the emotiveness of misinformation may have an indirect effect on the degree to which it spreads (and persists). Moreover, the effects of worldview that we reviewed earlier in this article provide an obvious departure point for future work on the link between emotion and misinformation effects, because challenges to people's worldviews tend to elicit highly emotional defense mechanisms (cf. E. M. Peters, Burraston, & Mertz, 2004).

Concerning individual differences, research has already touched on how responses to the same information differ depending on people's personal worldviews or ideology (Ecker et al., 2012; Kahan, 2010), but remarkably little is known about the effects of other individual-difference variables. Intelligence, memory capacity, memory-updating abilities, and tolerance for ambiguity are just a few factors that could potentially mediate misinformation effects.

Finally, concerning social networks, we have already pointed to the literature on the creation of cyber-ghettos (e.g., T. J. Johnson et al., 2009), but considerable research remains to be done to develop a full understanding of the processes of (mis-)information dissemination through complex social networks (cf. Eirinaki, Monga, & Sundaram, 2012; Scanfeld, Scanfeld, & Larson, 2010; Young, 2011) and of the ways in which these social networks facilitate the persistence of misinformation in selected segments of society.

Concluding Remarks: Psychosocial, Ethical, and Practical Implications

We conclude by discussing how misinformation effects can be reconciled with the notion of human rationality, before addressing some limitations and ethical considerations surrounding debiasing and point to an alternative behavioral approach for counteracting the effects of misinformation.

Thus far, we have reviewed copious evidence about people's inability to update their memories in light of corrective information and have shown how worldview can override fact and corrections can backfire. One might be tempted to conclude from those findings that people are somehow characteristically irrational, or cognitively "insufficient." We caution against that conclusion. Jern, Chang, and Kemp (2009) presented a model of belief polarization (which, as we noted earlier, is related to the continued influence of misinformation) that was instantiated within a Bayesian network. A Bayesian network captures causal relations among a set of variables: In a psychological context, it can capture the role of hidden psychological variables—for example, during belief updating. Instead of assuming that people consider the likelihood that hypothesis is true only in light of the information presented, a Bayesian network accounts for the fact that people may rely on other "hidden" variables, such as the degree to which they trust an information source (e.g., peer-reviewed literature). Jern et al. (2009) showed that when these hidden variables are taken into account, Bayesian networks can capture behavior that at first glance might appear irrational—such as behavior in line with the backfire effects reviewed earlier. Although this research can only be considered suggestive at present, people's rejection of corrective information may arguably represent a normatively rational integration of prior biases with new information.

Concerning the limitations of debiasing, there are several ethical and practical issues to consider. First, the application of any debiasing technique raises important ethical questions: While it is in the public interest to ensure that the population is well-informed, debiasing techniques can similarly be used to further *mis*inform people. Correcting misinformation is cognitively indistinguishable from misinforming people to replace their preexisting correct beliefs. It follows that it is important for the general public to have a basic understanding of misinformation effects: Widespread awareness of the fact that people may "throw mud" because they know it will "stick" is an important aspect of developing a healthy sense of public skepticism that will contribute to a well-informed populace.

Second, there are situations in which applying debiasing strategies is not advisable for reasons of efficiency. In our discussion of the worldview backfire effect, we argued that debiasing will be more effective for people who do not hold strong beliefs concerning the misinformation: In people who strongly believe in a piece of misinformation for ideological reasons, a retraction can in fact do more harm than good by ironically strengthening the misbelief. In such cases, particularly when the debiasing cannot be framed in a worldview-congruent manner, debiasing may not be a good strategy.

An alternative approach for dealing with pervasive misinformation is thus to ignore the misinformation altogether and seek more direct behavioral interventions. Behavioral economists have developed "nudging" techniques that can encourage people to make certain decisions over others, without preventing them from making a free choice (e.g., Thaler & Sunstein, 2008). For example, it no longer matters whether people are misinformed about climate science if they adopt ecologically friendly behaviors, such as by driving low-emission vehicles, in response to "nudges," such as tax credits. Despite suggestions that even these nudges can be rendered ineffective by people's worldviews (Costa & Kahn, 2010; Lapinski, Rimal, DeVries, & Lee, 2007), this approach has considerable promise.

Unlike debiasing techniques, behavioral interventions involve the explicit design of *choice architectures* to facilitate a desired outcome. For example, it has been shown that organ-donation rates in countries in which people have to "opt in" by explicitly stating their willingness to donate hover around 15–20%, compared to over 90% in countries in which people must "opt out" (E. J. Johnson & Goldstein, 2003). The fact that the design process for such choice architectures can be entirely transparent and subject to public and legislative scrutiny lessens any potential ethical implications.

A further advantage of the nudging approach is that its effects are not tied to a specific delivery vehicle, which may fail to reach target audiences. Thus, whereas debiasing requires that the target audience receive the corrective information—a potentially daunting obstacle—the design of choice architectures automatically reaches any person who is making a relevant choice.

We therefore see three situations in which nudging seems particularly applicable. First, when behavior changes need to occur quickly and across entire populations in order to prevent negative consequences, nudging may be the strategy of choice (cf. the Montreal Protocol to rapidly phase out CFCs to protect the ozone layer; e.g., Gareau, 2010). Second, as discussed in the previous section, nudging may offer an alternative to debiasing when ideology is likely to prevent the success of debiasing strategies. Finally, nudging may be the only viable option in situations that involve organized efforts to deliberately misinform people—that is, when the dissemination of misinformation is programmatic (a case we reviewed at the outset of this article, using the examples of misinformation about tobacco smoke and climate change).

In this context, the persistence with which vested interests can pursue misinformation is notable: After decades of denying the link between smoking and lung cancer, the tobacco industry's hired experts have opened a new line of testimony by arguing in court that even after the U.S. Surgeon General's conclusion that tobacco was a major cause of death and injury in 1964, there was still "room for responsible disagreement" (Proctor, 2004). Arguably, this position is intended to replace one set of well-orchestrated misinformation—that tobacco does not kill—with another convenient myth—that the tobacco industry did not know it. Spreading doubts by referring to the uncertainty of scientific conclusions—whether about smoking, climate change, or GM foods—is a very popular strategy for misinforming the populace (Oreskes & Conway, 2010). For laypeople, the magnitude of uncertainty does not matter much as long as it is believed to be meaningful. In addition to investigating the cognitive mechanisms of misinformation effects, researchers interested in misinformation would be well advised to monitor such sociopolitical developments in order to better understand why certain misinformation can gain traction and persist in society.

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Notes

1. We use the term "misinformation" here to refer to any piece of information that is initially processed as valid but that is subsequently

retracted or corrected. This is in contrast to so-called *post-event misinformation*, the literature on which has been reviewed extensively elsewhere (e.g., Ayers & Reder, 1998, Loftus, 2005) and has focused on the effects of suggestive and misleading information presented to witnesses *after* an event.

2. There is ongoing debate about whether the effects of worldview during information processing are more prevalent among conservatives than liberals (e.g., Greenberg & Jonas, 2003; Jost, Glaser, Kruglanski, & Sulloway, 2003a; Jost, Glaser, Kruglanski, & Sulloway, 2003b). This debate is informative and important but not directly relevant in this context. We are concerned with the existence of worldview-based effects on information processing irrespective of their partisan origin, given that misinformation effects are generic.

3. Two of the authors of this article (Cook & Lewandowsky, 2011) have prepared a practitioner's guide to debiasing that, in 7 pages, summarizes the facets of the literature that are particularly relevant to practitioners (e.g., scientists and journalists). The booklet is available for free download in several languages (English, Dutch, German, and French as of July 2012) at http://sks.to/debunk, and can be considered an "executive summary" of the material in this article for practitioners.

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Misinformation and How to Correct It

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Abstract

The increasing prevalence of misinformation in society may adversely affect democratic decision making, which depends on a well-informed public. False information can originate from a number of sources including rumors, literary fiction, mainstream media, corporate-vested interests, governments, and nongovernmental organizations. The rise of the Internet and user-driven content has provided a venue for quick and broad dissemination of information, not all of which is accurate. Consequently, a large body of research spanning a number of disciplines has sought to understand misinformation and determine which interventions are most effective in reducing its influence. This essay summarizes research into misinformation, bringing together studies from psychology, political science, education, and computer science. Cognitive psychology investigates why individuals struggle with correcting misinformation and inaccurate beliefs, and why myths are so difficult to dislodge. Two important findings involve (i) various "backfire effects," which arise when refutations ironically reinforce misconceptions, and (ii) the role of worldviews in accentuating the persistence of misinformation. Computer scientists simulate the spread of misinformation through social networks and develop algorithms to automatically detect or neutralize myths. We draw together various research threads to provide guidelines on how to effectively refute misconceptions without risking backfire effects.

INTRODUCTION

Misinformation by definition does not accurately reflect the true state of the world. In the present context, we apply the term misinformation to information that is initially presented as true but later found to be false (cf. Lewandowsky, Ecker, Seifert, Schwarz, & Cook, 2012). For example, one might initially believe a news report that a causal link has been found between use of deodorants and breast cancer but find out later that this is (most likely) just a myth.

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There are several reasons why misinformation has a more potentially damaging effect than ignorance, that is, the absence of knowledge. (i) Misinformation can be actively disseminated with an intent to deceive (it is then sometimes referred to as *dis*information). For example, antiscience campaigns misinform the public on issues that have achieved consensus among the scientific community, such as biological evolution, and the human influence on climate change. However, an intention to deceive need not always be present—for example, news coverage of unfolding events by its very nature requires regular updating and correcting of earlier information (e.g., the death toll after a natural disaster). (ii) False beliefs based on misinformation are often held with strong conviction, which is rarely the case with ignorance. For example, people who reject climate science also believe they are the best informed about the subject. (iii) Misinformation is often immune to correction. Despite clear retractions, misinformation and associated false beliefs may continue to influence people's reasoning and judgments. This continued influence can be observed even when people explicitly remember and believe the retractions. Misinformation may thus adversely affect decision making in democratic societies that depend on a well-informed public.

The psychological and social implications of misinformation have been under investigation for decades, although interest has intensified in recent years, arguably because misinformation has an increasing presence in society and its adverse consequences can no longer be overlooked. The meteoric rise of social media, the acceleration of news cycles, and the fragmentation of the media landscape have facilitated the dissemination of misinformation.

Accordingly, much research has explored how misinformation originates and propagates through society, and what its effects are at a societal level. We focus on how misinformation unfolds its effects at the level of the individual. This requires research into the psychology of how a person accesses information and updates memories and beliefs, and how this is affected by cultural factors and worldviews. Applied research has been looking into the effectiveness of various intervention techniques to determine which methods are most effective in reducing the influence of misinformation and how technology can help achieve this.

Understanding misinformation is a multidisciplinary topic, where cultural values, individual cognition, societal developments, developing technology, and evolving media all come into play. Therefore, reducing the influence of misinformation requires a multidisciplinary response, synthesizing the findings of social and political science, information and computer science, and psychology.

FOUNDATIONAL RESEARCH

Sources of Misinformation

False information can derive from a number of sources, and the analysis of the origin and dissemination of misinformation has yielded a new field known as "agnotology": the study of culturally produced ignorance and misinformation-driven manufactured doubt (Proctor, 2008).

Misinformation can be disseminated even by seemingly counterintuitive sources. For example, straightforward fiction is effective at implanting misinformation, even when readers are warned beforehand that the content is nonfactual. This is especially concerning when a writer pretends to base fictional work on a scientific basis, thereby misrepresenting the science (e.g., Michael Crichton's novel *State of Fear*, which grossly distorts climate science).

Rumours and urban myths are further significant sources of misinformation that tend to produce "sticky" memes that resist subsequent correction. Social media websites and blogs, which allow the bypassing of traditional gatekeepers such as professional editors or peer reviewers, have contributed to the increased dissemination of such misinformation.

Moreover, Internet content is fast becoming a replacement for expert advice, with a majority of Americans looking online for health information. However, numerous analyses of online content have found that a significant proportion of websites provide inaccurate medical information. Likewise, the quality of information from mainstream media (e.g., newspapers, TV), and thus the standard of consumers' knowledge depends strongly on the news outlet.

Another potential source of bias, ironically, is the media's tendency to present balanced coverage by giving equal weight to both sides of a story. This can result in "balance as bias," when domain experts are given equal voice with nonexperts.

While misinformation can originate inadvertently from all those channels, they can also be used to plant and disseminate misinformation in a targeted manner. For example, to promote their case for the invasion of Iraq in 2003, the Bush administration announced that there was no doubt that Saddam Hussein had weapons of mass destruction (WMDs) and linked Iraq with the 9/11 terrorist attacks. Even though both assertions are now known to have been false, a significant percentage of Americans continued to believe that WMDs had been found in Iraq even after the post-invasion search failed to turn up any WMD, and around half of Americans endorsed (nonexistent) links between Iraq and al-Qaida.

Finally, there is evidence that corporate-vested interests have engaged in deliberate campaigns to disseminate misinformation. The fossil-fuel industry, for example, has demonstrably campaigned to sow confusion about the impact of fossil fuels on the environment, and tobacco manufacturers have promoted misinformation about the public health impacts of smoking.

IDENTIFYING MYTHS AND MISCONCEPTIONS

Identifying and analyzing the content and rhetorical arguments of misinformation is a necessary step toward understanding misconceptions and developing appropriate interventions. Taxonomically organizing the misinformation landscape allows deeper exploration of root causes, provides insights into the psychology of misconceptions, and can assist in identifying potential policy implications of inaccurate information. Most important, it provides a framework for developing effective refutation strategies.

Foundational work on taxonomies dates back to Aristotle, who defined the first taxonomy of logical fallacies by dividing them into those that are dependent on language (e.g., ambiguity: using a word or phrase that can have more than one meaning) and those that are not (e.g., sweeping generalization). Gilovich (1991) sorted reasoning flaws into two main categories—cognitive (resulting from the tendency to find order in random data) and motivational/social (wishful thinking or self-serving distortions of reality). This taxonomy has been applied, for example, to the most common antivaccine myths (Jacobson, Targonski, & Poland, 2007). In another domain, Rahmstorf (2004) categorized climate skepticism into three types: trend (climate change is not happening), attribution (climate change is not caused by humans), and impact (impacts from climate change are inconsequential).

The benefits of the taxonomical approach can be illustrated with an analysis of myths associated with the burning of charcoal in sub-Saharan Africa (Mwampamba, Ghilardi, Sander, & Chaix, 2013). By taxonomically organizing a diverse set of myths, the authors identified the root problem (conflation of charcoal with wood-based fuels), provided policy consequences of each myth, and recommended responses. For example, the myth that "charcoal is used only by the poor" had resulted in interventions that targeted the wrong user groups. By dispelling this misconception, communicators were able to target interventions more appropriately.

Despite the diversity of taxonomies, arguably one of the more useful and applicable taxonomies is a general approach applied to a number of domains. A broader synthesis has identified five common characteristics across a number of movements that deny a well-supported scientific fact: fake experts, cherry picking, unrealistic expectations, logical fallacies, and conspiracy theories (Diethelm & McKee, 2009). There is a deeper psychological reason why this is a potentially effective approach: providing an alternative explanation for how misinformation originates is an important element to refutation, as explored in subsequent sections on retraction techniques. To understand why this is important, we need to examine the psychological challenges in reducing the influence of misinformation.

Challenges in Retracting Misinformation

Misinformation is surprisingly resilient to correction or retraction. In some cases, refutations have actually reinforced misconceptions. Such ironic reinforcements of false information are known as "backfire" or "boomerang" effects. Even when corrections do not backfire, people often cling to misinformation in the face of a retraction, a phenomenon known as the Continued Influence Effect.

In a commonly used experimental design, participants are presented with a news report that describes an unfolding event, such as a fire or a robbery. A critical piece of information (e.g., the cause of the fire) is provided but later retracted (i.e., the earlier information is identified as being incorrect). People's reliance on the retracted information is then measured with inference questions (e.g., "why was there so much smoke?"). Studies using this paradigm show that retractions rarely have the intended effect of eliminating reliance on misinformation, even when participants remember the retraction. People draw inferences from the same discredited information whose correction they explicitly acknowledge.

One explanation of the lingering effects of misinformation invokes the notion that people build mental models of unfolding events. If a central piece of the model is invalidated, people are left with a gap in their model, while the invalidated piece of information remains accessible in memory. When questioned about the event, people often use the still readily available misinformation rather than acknowledge the gap in their understanding.

There are several cases in which attempts to correct misinformation have been shown to actually reinforce them. For example, in an experiment where people were exposed to health claims that were either labeled valid or invalid, after a delay of 3 days, older people classified 40% of repeatedly encountered invalid claims as valid. This represents one instance of the "familiarity backfire effect," when refutations make a myth more familiar.

There is also suggestive evidence that refutations may backfire when they become too complex, an effect described as an "overkill backfire effect." For example, researchers have found that asking people to generate a few arguments for why their belief may be wrong was successful in changing a belief, whereas generating *many* counterarguments reinforced the belief. People generally prefer simple explanations over complicated ones, and hence when it comes to refutations, less might sometimes be more.

SUCCESSFUL RETRACTION TECHNIQUES

Three techniques have been identified to date that can make retractions of misinformation more effective. First, reliance of misinformation can be reduced if people are explicitly warned about possibly being misinformed at the outset. Advanced warnings put the person cognitively on-guard so they are less likely to be influenced by the misinformation.

Second, retractions are more effective if they are repeated or strengthened. Especially if misinformation is encoded strongly, repeating the retraction helps reduce the misinformation effect although it does not necessarily eliminate it. However, strengthening of the initial misinformation seems to have a stronger *negative* effect than strengthening of the retraction has a *positive* effect. This unfortunate asymmetry results in an unlevel playing field, with a seemingly natural advantage ceded to initially encoded misinformation.

Third, corrections should provide an alternative explanation that fills the gap created by the retraction. An effective alternative explanation is plausible, it explains the causal chains in the initial report, it explains why the misinformation was initially thought to be correct, and it explains the motivation behind the misinformation. An effective alternative explanation is also simpler (or at least not more complicated) than the misinformation.

ADDRESSING MISCONCEPTIONS IN EDUCATION

A key element of education is conceptual change, a large part of which involves the correction of misconceptions. This is all the more important as misconceptions can interfere with new learning. For these reasons, educators seek to address misconceptions despite the inherent risks associated with ineffective or backfiring retractions.

Fortunately, there is a growing literature on the explicit refutation of misinformation as an educational tool. A number of studies have explored the effectiveness of different classroom interventions designed to reduce misconceptions. Thorough evidence-based refutations were found to be significantly more effective than nonrefutational lessons (Guzzetti, Snyder, Glass, & Gamas, 1993). That is, in refutation-style lectures, misconceptions were first activated and then immediately countered with accurate information. Nonrefutational lectures, by contrast, would teach the accurate information without any reference to the misconceptions. The former was found to be far more effective.

Refutation in the classroom can be an opportunity to foster critical thinking, encouraging students to skeptically assess empirical evidence and draw valid conclusions from the evidence. Use of multimedia in combination with refutational formats has shown to be more effective than standard lecture formats in reducing physics misconceptions (see Ecker, Swire, & Lewandowsky, 2014, for a review).

Thus, while there is a danger of a familiarity backfire effect by familiarizing students with misconceptions, this research demonstrates that activating myths followed by immediate refutations—combining a retraction with a detailed explanation—can be an effective way to induce conceptual change.

CUTTING-EDGE RESEARCH

Research into misinformation has recently extended into other disciplines. Computer scientists have developed models to simulate the spread of misinformation and detect disinformation in real time. Cognitive scientists are investigating the role of attitudes and worldviews in accentuating the persistence of misinformation.

Computer Science and Misinformation

When Charles Spurgeon quipped in 1859 that "a lie will go round the world while truth is pulling its boots on," he could scarcely have imagined the speed with which information is exchanged in the Twitter age. Spam is one form of misinformation and is often posted on social media sites such as Twitter. While moderators seek to quickly remove spam URLs, tweets are viewed with such speed that over 90% of visitors will have viewed a spam tweet before the link could be removed.

Computer science provides tools that can illuminate the nature and reach of misinformation. For example, a content analysis of 1000 Twitter status updates matching terms such as "cold + antibiotics" was used to explore misconceptions related to antibiotics. Tweets demonstrating misunderstanding or misuse of antibiotics were found to reach 172,571 followers. Conversely, health providers are being encouraged to use social networks to communicate with patients and people seeking health information.

Computer scientists are developing algorithms that can identify intentionally disseminated misinformation in real time. There are a series of cognitive, psychological, and emotional cues associated with false intent that make it possible to automatically detect misinformation without having to rely on domain knowledge. Software such as a Linguistic Pattern Analyzer can be programmed to scan linguistic patterns to detect disinformation and locate the sources (Mack, Eick, & Clark, 2007).

For example, one form of misinformation gaining prominence in recent years is deceptive opinion spam, such as fictitious consumer reviews written to appear authentic. Deceptive text can be automatically detected using a combination of text categorization, classifiers and psycholinguistic deception, and has been found to accurately detect nearly 90% of deceptive opinion spam (Ott, Choi, Cardie, & Hancock, 2011). This outperforms most human judges.

Social network analysis allows researchers to simulate the spread of misinformation through a network with a model adopting traits similar to the spread of a disease across a population. This approach also allows researchers to model ways to limit the spread of misinformation. For example, researchers can simulate how one might select a small number of "early adopters" in a network in order to trigger the spread of positive information, minimizing the number of people who adopt negative information. Social network algorithms can compute which nodes in a network are most effective in blocking negative influences (Nguyen *et al.*, 2012).

An exciting new area of research is the incorporation of other disciplines into computer science. Social network analysis typically considers who is connected to whom to determine how information diffuses through a network. However, one must also consider the cultural values of the people in the network and the relevance of the misinformation to their values. This is particularly important when culturally relevant information disseminates through a network. It turns out that research into the role of cultural values and worldview has taken center stage in advancing our understanding of how people process misinformation and react to retractions.

THE ROLE OF CULTURAL VALUES AND WORLDVIEW

Worldviews and ideology have been shown to influence basic cognitive processes and shape attitude formation. For example, conservatives pay more attention to negative information (e.g., threatening or antisocial behavior) compared to liberals. This causes conservatives to place more weight on negative behavior of numerically smaller groups, which may explain why conservatives are more likely to form negative attitudes toward social minorities.

Research is also revealing a strong role of worldview in how people process and retain misinformation. For example, Democrats are more likely to believe statements underplaying the risks of higher oil prices, whereas Republicans are more likely to believe myths concerning President Obama's birthplace.

Similarly, retractions of politically relevant misperceptions were found effective only if the retraction supported the person's political orientation. However, when the retraction conflicted with a person's ideology, a "worldview backfire effect" was sometimes observed where the retraction caused stronger adherence to the misinformation. For example, correcting the misconception that President G. W. Bush's tax cuts in the 2000s increased government revenue led to a backfire effect among Republican participants.

When confronted with information compellingly debunking a preexisting belief, only a minute proportion of people—2% of participants in one study—explicitly acknowledged their beliefs were mistaken. The majority of people, however, displayed some form of motivated reasoning by counterarguing against the refutation. This is consistent with other research into "motivated skepticism," which shows participants expressing active skepticism to worldview-incongruent information. The most intransigent people engage in a strategy termed "disputing rationality": insisting on one's right to an opinion without it being supported by factual reasoning.

Associated with the worldview backfire effect is a phenomenon known as belief polarization. This occurs when the same information results in people with contrasting prior beliefs to update their beliefs in opposite directions. For example, when presented with supporting and opposing information about the death penalty, participants rated arguments that confirmed their own beliefs to be more convincing and consequently strengthened prior beliefs. Polarization is also observed across education levels concerning views on climate change or beliefs that President Obama is a Muslim.

This summary of worldview effects demonstrates how preexisting attitudes and beliefs can affect the processing of misinformation and its retraction. In our view, it is the motivated reasoning fueled by worldviews that presents the main obstacle to efficient debiasing, and hence the greatest challenge for future research into misinformation.

KEY ISSUES FOR FUTURE RESEARCH

Worldview

There is a need for further research into interventions that reduce the biasing influence of worldview. Ecker, Lewandowsky, Fenton, and Martin (2014) argued that worldview will have a strong influence on the acceptance of counterattitudinal retractions only if accepting the retraction requires a change in attitudes. In other words, the worldview backfire effect may not be ubiquitous, and counterattitudinal retractions will be (relatively) effective as long as a person can accommodate the retraction within their more general belief framework. For example, an ethnically prejudiced person could readily accept that a particular crime was *not* committed by an immigrant but still believe that most immigrants are criminals. In contrast, for a Republican it would actually require some shift in attitude toward President Bush to acknowledge that his tax cuts were ineffective and his claims to the contrary were incorrect.

Furthermore, Ecker *et al*. (2014) proposed that part of the empirical discrepancy regarding worldview effects may lie in the difficulty of measuring beliefs. That is, under some circumstances people may change their underlying attitudes but not acknowledge that change in order to "save face." Worldview backfire effects could then occur when people overcompensate, that is, explicitly state that their belief has grown stronger when (or because) in fact it has decreased.

Some preliminary research indicates that the source of the retraction is important; for example, corrections of the death-panel myth were effective among Republicans primarily when communicated by a Republican politician. "Cultural cognition" theory shows that framing information in worldview-consonant terms can effect positive belief change. For example, opponents of climate science respond more positively if climate action is presented as a business opportunity for the nuclear industry rather than a regulatory burden involving emission cuts. Even simple wording changes such as "carbon offset" instead of "carbon tax" has a positive effect among Republicans whose values are challenged by the word "tax."

One of the underlying cognitive processes that distinguish conservatives from liberals is an emphasis on different moral principles, with liberals placing more value on harm prevention and equality. Thus, liberals view the environment in moral terms, whereas conservatives do not. Research has shown that the effect of ideology on environmental views can be neutralized by reframing pro-environmental rhetoric in terms of purity, a moral value highly emphasized by conservatives (Feinberg & Willer, 2013). Exploring the role of moral intuitions in framing politically charged issues is an area of future research.

An alternative approach to this kind of "worldview-affirmation" is self-affirmation. In one study, participants were asked to write about a time they felt good about themselves because they acted on an important personal value. Self-affirmed people were more receptive to messages that threatened their worldviews. Likewise, reminding people of the diversity of attitudes in their frame of reference can make them more open to consider counterattitudinal information (Levitan & Visser, 2008).

While these avenues to reduce worldview-associated biases in information processing are worth pursuing, some researchers have also argued that the effects of worldview are so difficult to overcome that approaches to target behavior-change directly, bypassing attitude and belief change, are more promising. These approaches include the creation of choice architectures, such as "opt-out" rather than "opt-in" organ donation schemes, and the use of government-controlled taxation or financial incentives. For example, using taxes to raise the price of alcohol has been shown to be an effective means of reducing drinking (Wagenaar, Salois, & Komro, 2009).

More research is required on experimentally testing different refutation structures, and more work is needed to create a solid empirical database on which to base recommendations. For example, evidence for the familiarity backfire effect in young adults is somewhat mixed, so further research could clarify its boundary conditions. Existing studies finding an overkill backfire effect were based on asking participants to generate a small or large number of counterarguments, but an examination more applicable to real-world situations would involve presenting prewritten counterarguments to experimentally measure the relative impact of different refutation formats. Future research should explore under what conditions the overkill backfire effect and familiarity backfire effects arise, and it should clarify the role of expertise and trustworthiness of the source of the refutation.

There is much potential in the interdisciplinary approach of integrating psychological research with other disciplines. Experimental clarification is needed concerning the conditions under which the refutation of misconceptions can be expected to be beneficial for educational purposes, as reviewed earlier, and when refutations run the risk of producing a familiarity backfire effect. Similarly, integrating psychology with computer science presents exciting opportunities to respond to misinformation in innovative new ways.

Future Trends in Computer Science and Misinformation

Social network analysis offers the opportunity to investigate how misinformation propagates through a network and offers methods to reduce the spread of misinformation across a network. This research can lead to the development of tools that permit investigation into how misinformation propagates and persists through social networks. Potentially, this may lead to practical applications that facilitate the neutralization of or "inoculation" against misinformation by identifying influential members of a network to efficiently disseminate accurate information. This approach is of particular interest, given that it has been shown that the effectiveness of misinformation campaigns can be reduced through preemptive inoculation (Pfau, Haigh, Sims, & Wigley, 2007).

As seen in the previous section, cultural values and worldview play a significant role in how people retain misinformation. A further area of future research is the incorporation of other disciplines such as psychology into social network analysis. One approach takes into account the impact of cultural values, as culturally relevant information disseminates through a network (Yeaman, Schick, & Lehmann, 2012). Another interesting method is the combination of social network analysis with social and psychological characteristics of people. An example is the combination of an agent-based model employing an iterative learning process (where people repeatedly receive information and gradually update their beliefs) with social network analysis to determine how nodes (e.g., people) in a social network would be influenced by the spread of misinformation through the network (Monakhov *et al.*, 2012).

An area of future research is the development of more sophisticated and accurate tools that can detect and respond to online misinformation. An example of such a tool is *Truthy*, a system originally designed to detect orchestrated misinformation campaigns on Twitter. Similarly, the browser extension *Dispute Finder* examines text on a webpage, and drawing upon a database of known disputed claims highlights disputed information. The advantage of this approach is that tagging misinformation as false at the time of initial encoding reduces the likelihood that the misinformation shows persistence. Research should also measure the effectiveness of these tools, particularly across different demographics, to determine how the effectiveness of such interventions may vary for people of different worldview or background.

The practice of automatically detecting and responding to misinformation does come with risks. One experiment that issued real-time corrections of political misinformation found that the corrections had a positive effect for people whose attitudes were predisposed against the misinformation. However, the real-time correction was less effective than a delayed correction among those whose political beliefs were threatened by the correction (Garrett & Weeks, 2013). One approach to mitigate this risk would be to couch corrections in positive terms.

Understanding and Formalizing Misperceptions

To design appropriate intervention strategies, researchers need to identify which misconceptions are most prevalent. A survey of climate views adopting Rahmstorf's (2004) "trend/attribution/impact" taxonomy found that different types of skepticism are strongly interrelated (Poortinga, Spence, Whitmarsh, Capstick, & Pidgeon, 2011): those who were skeptical about one aspect of climate change (e.g., attribution skepticism, i.e., skepticism that humans are causing climate change) were more likely to be skeptical about other aspects of climate change (e.g., trend skepticism, or skepticism that climate change is occurring). Understanding that it is a minority of people holding all kinds of misconceptions (rather than many people holding different, singular misconceptions) is clearly informative for both intervention strategies and policy implementation.

While taxonomies classify misperceptions into hierarchical categories, another method of formalizing misinformation is the development of ontologies. These involve defining a set of properties for specific myths or misperceptions (e.g., motivation, type, channel, profile of misinformer). The Web Ontology Language is a standard for defining ontologies and has been used to develop a digital misinformation library (Zhou & Zhang, 2007). Such a library can be used to increase public awareness of misinformation and be imported into algorithms that automatically detect patterns of misinformation.

In conclusion, the combined contribution of information and computer science to misinformation research is a clear demonstration of the importance of a multidisciplinary approach to understanding and refuting misinformation. More broadly, the integration of psychological, political, and computer science offers the potential of implementing the insights of cognitive science in practical, real-world applications.

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http://www.shapingtomorrowsworld.org/inthemedia.htm.

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Countering Climate Science Denial and Communicating Scientific Consensus

John Cook

Summary

Scientific agreement on climate change has strengthened over the past few decades, with around 97% of publishing climate scientists agreeing that human activity is causing global warming. While scientific understanding has strengthened, a small but persistent proportion of the public actively opposes the mainstream scientific position. A number of factors contribute to this rejection of scientific evidence, with political ideology playing a key role. Conservative think-tanks, supported with funding from vested interests, have been and continue to be a prolific source of misinformation about climate change. A major strategy by opponents of climate mitigation policies has been to cast doubt on the level of scientific agreement on climate change, contributing to the gap between public perception of scientific agreement and the 97% expert consensus. This "consensus gap" decreases public support for mitigation policies, demonstrating that misconceptions can have significant societal consequences. While scientists need to communicate the consensus, they also need to be aware of the fact that misinformation can interfere with the communication of accurate scientific information. As a consequence, neutralizing the influence of misinformation is necessary. Two approaches to neutralize misinformation involve refuting myths after they have been received by recipients (debunking) or pre-emptively inoculating people before they receive misinformation (prebunking). Research indicates pre-emptive refutation or “prebunking” is more effective than debunking in reducing the influence of misinformation. Guidelines to practically implement responses (both pre-emptive and reactive) can be found in educational research, cognitive psychology, and a branch

of psychological research known as inoculation theory. Synthesising these separate lines of research yields a coherent set of recommendations for educators and communicators. Clearly communicating scientific concepts, such as the scientific consensus, is important but scientific explanations should be coupled with inoculating explanations of how that science can be distorted.

The strengthening scientific consensus on human-caused global warming

A number of studies have attempted to quantify the level of agreement amongst scientific experts about anthropogenic global warming (AGW), defined as the attribution of human activities to the rise in the average global temperature since the mid-20th Century. These include surveys of the scientific community (Carlton et al., 2015; Doran and Zimmermann, 2009; Verheggen et al., 2014), analyses of public statements by scientists (Anderegg et al., 2010) and analyses of peer-reviewed papers about global climate change (Cook et al., 2013; Oreskes, 2004; Shwed & Bearman, 2010). Surveys that categorize different levels of expertise in climate science consistently find that higher expertise in climate science corresponds to higher consensus on AGW, as visualised in Figure 1 (taken from Cook et al., in press). A number of studies find that for the group with the highest level of expertise, namely scientists who publish peer-reviewed climate research, 97% agree that humans are causing global warming.

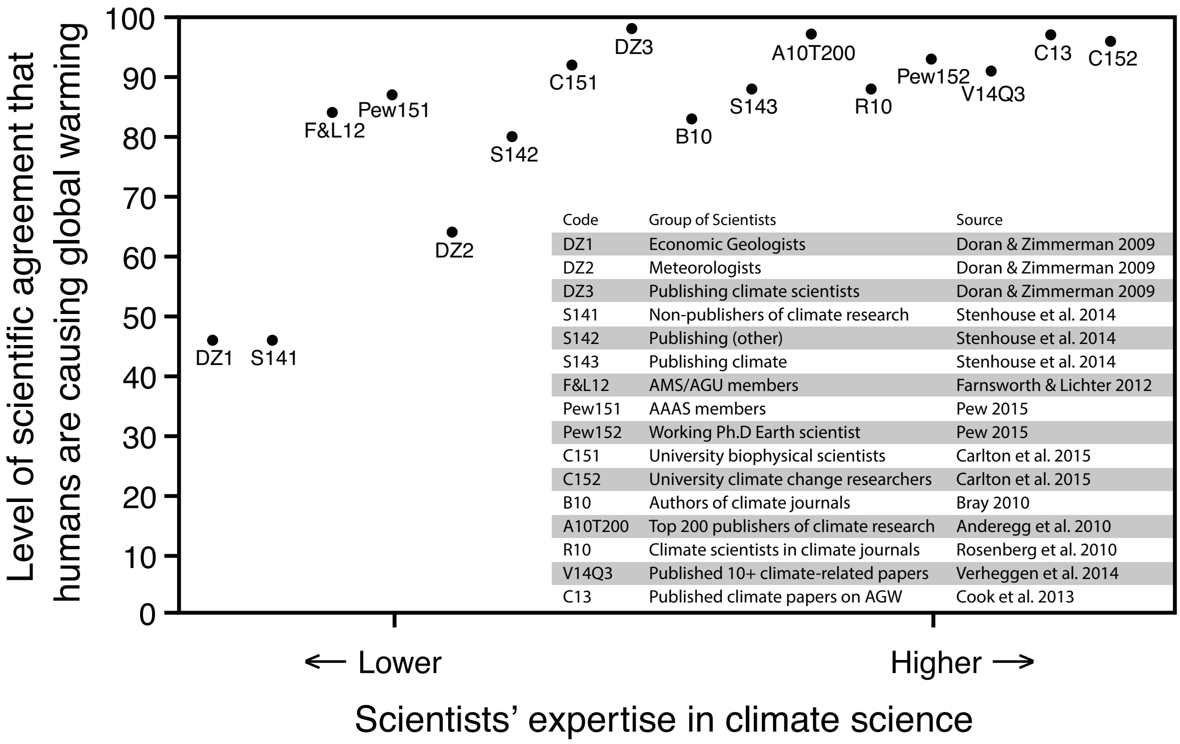

Figure 1: Level of scientific agreement that humans are causing global warming among scientific groups of varying expertise in climate science. (Cook et al., in press).

In addition, scientific agreement on AGW has been observed to strengthen over time. Mathematical analysis of citation networks found that consensus in climate papers had formed in the early 1990s (Shwed & Bearman, 2010). Similarly, analysis of the abstracts of climate papers from 1991 to 2011 found that a strong consensus on AGW had already formed in the scientific literature by 1991, and strengthened over the next two decades (Cook et al., 2013).

The strengthening consensus is reflected in the statements of the Intergovernmental Panel on Climate Change (IPCC). Figure 2 shows how the IPCC has issued progressively stronger statements regarding the role of human activity in recent global warming. The Second Assessment Report stated, "[t]he balance of evidence suggests that there is a discernible human influence on the global climate" (Houghton et al., 1996). This position was strengthened in the

Third Assessment Report in 2001, reporting over 66% probability that "most of the warming observed over the last 50 years is attributable to human activities" (Houghton et al., 2001). The strongest IPCC statement on attribution comes in the most recent Fifth Assessment Report, reporting over 95% confidence that human activity caused global warming since the mid-20th century (Qin et al., 2014).

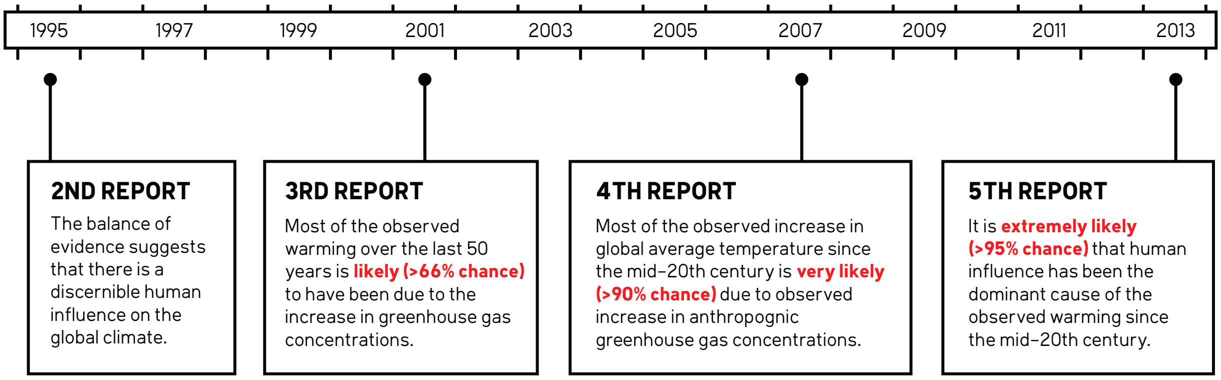

Figure 2: Strengthening IPCC statements on attribution of human activity to recent global warming (Houghton et al., 1996; Houghton et al., 2001; Solomon et al., 2007; Qin et al., 2014)

Despite the strengthening consensus in the scientific community and scientific literature, a small group consisting mostly of non-climate scientists persistently rejects mainstream climate science (Oreskes & Conway, 2011). In order to effectively address the impact of misinformation on climate literacy levels, one needs to understand the nature and drivers of climate science denial.

Attributes and drivers of climate science denial

In this chapter, climate science denial is defined as the rejection of the scientific consensus on either the existence of global warming, the role of humanity in causing global warming or the impacts of climate change on society and the environment. These three aspects of denial are labelled by Rahmstorf (2004) as trend, attribution or impact skepticism (although in this chapter, the term ‘skepticism’ is deemed inaccurate when used to characterise the process of science denial). Poortinga et al. (2011) found that the different stages of denial are strongly interrelated, with rejection of one aspect of climate science (i.e., attribution denial) associated with rejection of other aspects of climate science (i.e., trend denial). ‘Interrelated denial’ results in an incoherent scientific understanding, with contradictory arguments simultaneously espoused by people who deny climate science (Cook, 2014; Lewandowsky, 2015).

The overarching categories of trend, attribution and impact denial expand into a comprehensive array of arguments against the realities of climate change. An expanded version of the taxonomy, taken from SkepticalScience.com (Figure 3), was adopted by Elsasser and Dunlap (2012) who analysed climate misinformation published by syndicated conservative columnists. They found that the most popular argument adopted by conservative columnists from 2007 to 2010 was “there is no consensus.” As shall be examined later in this chapter, perceived consensus has been observed to be a strong predictor of perceptions about climate trends, attribution and impacts.

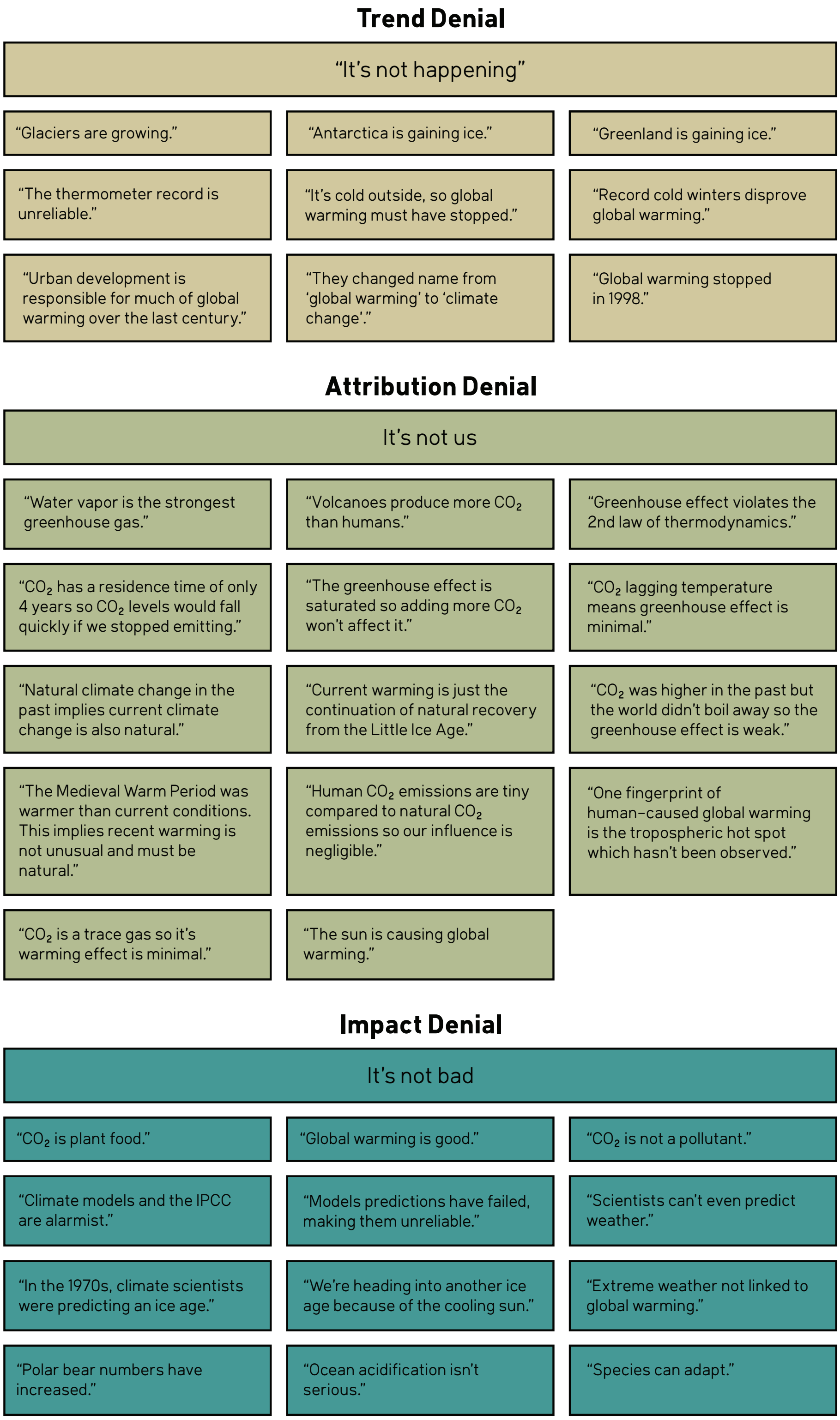

Figure 3: A taxonomy of climate myths refuted in the online course Denial101x (Cook et al., 2015b).

Rejection of climate science is not uniform across the planet. One global survey found that climate science acceptance varied across countries, being lowest in Australia, New Zealand, Norway and the USA (Tranter & Booth, 2015). Another survey found that acceptance of global warming was much lower in the USA and UK compared to countries such as Japan, Argentina, Italy, Sweden, Canada and Germany (Pelham, 2009). A striking result from this finding was that self-reported knowledge about climate change did not always correlate with acceptance of AGW. For example, 97% of Americans report some knowledge about global warming while only 49% agree that rising temperatures are a result of human activities. This implies that lack of knowledge is not the only factor driving rejection of AGW (Kahan et al., 2012b).

What are the other factors driving climate science denial? Gifford (2011) coined the term "dragons of inaction" to describe psychological barriers preventing people from being concerned about climate change. Gifford lists many dragons of inaction, including optimism bias (underestimating risk), pessimism bias (underestimating personal efficacy) and psychological distance (discounting events that are perceived to be far away).

A number of studies have found that political ideology is one of the dominant drivers of climate beliefs (Heath & Gifford, 2006; Kahan, Jenkins-Smith, & Braman, 2011; Lewandowsky, Oberauer, & Gignac, 2013; Stenhouse et al., 2013). Political ideology has been measured in a variety of ways whether it be party affiliation (Hardisty, Johnson, & Weber, 2010), the degree of support for free, unregulated markets (Heath & Gifford, 2006), a score on a liberal-conservative scale (McCright, Dunlap, & Xiao, 2013) or on a two-dimensional scale of "hierarchical-individualist" versus "egalitarian-communitarian" (Kahan, Jenkins-Smith, & Braman, 2011).

While climate belief varies across countries, an affiliation with conservative political parties is a consistent predictor of scepticism (Tranter & Booth, 2015). Fundamentally, the psychological mechanism involved is not aversion to the problem of climate change but aversion to the proposed solutions to mitigate climate change. Accepting the scientific evidence that human activity is causing global warming is commonly framed as requiring behavioural and societal changes, such as increased regulation of industry. These types of changes are perceived to be inconsistent with conservative values, such as liberty or small government. This causal link was teased out in an experiment that presented regulation of polluting industries or nuclear energy as two possible solutions to climate change. Amongst political conservatives, the nuclear energy message had a positive effect on climate attitudes while the regulation message caused a backfire effect, lowering acceptance of climate change (Campbell & Kay, 2014).

Political ideology plays a strong role in attitudes towards climate change, with cultural values influencing the formation of climate beliefs (Kahan, Jenkins-Smith, & Braman, 2011) as well as the selection of media and information sources (Feldman, Myers, Hmielowski, & Leiserowitz, 2014). Nevertheless, the positive effect of climate information (or conversely, the negative effect of misinformation) still plays a significant role in influencing climate literacy levels (Bedford, 2015). The next section offers a brief history of misinformation about climate change and the psychological impact of misinformation.

The impact of misinformation

Although climate change has become a highly polarized issue in countries such as the U.S. (McCright & Dunlap, 2011), this has not always been the case. President George H.W. Bush once pledged to “fight the greenhouse effect with the White House effect” (Peterson, 1989, p. A1). What transformed a bipartisan issue into a highly charged, polarized public debate? A major contributor to this transformation has been the strategic use of misinformation by various political groups and actors.

Conservative think tanks started producing climate change misinformation at prolific levels in the early 1990s (Jacques, Dunlap, & Freeman, 2008). A sharp increase in the number of misleading publications in the 1990s coincided with international efforts to reduce carbon emissions (McCright & Dunlap, 2000). At the same time, public skepticism about global warming increased, suggesting that the misinformation campaign had been effective (Nisbet & Myers, 2007). Allied with conservative groups were the fossil-fuel industry, who campaigned to sow confusion about the environmental impact of fossil fuels (Jacques, Dunlap, & Freeman, 2008; Farrell, 2015a; Farrell, 2015b). An analysis of 91 organisations that disseminate climate misinformation found that from 2003 to 2010, these groups received an average total income of over $900 million per year (Brulle, 2014), though this funding was provided for activities relative to a broad range of policy issues, rather than exclusively climate change.

The scientific consensus has been a focal point for the misinformation campaign. Opponents of climate action have manipulated public perception of the expert consensus for more than two decades through active campaigns to manufacture doubt. In the early 1990s, a fossil fuel organization spent half a million dollars on a campaign to cast doubt on the consensus (Oreskes, 2010). An analysis of conservative op-eds, which are a prolific source of climate misinformation, found that the most frequently repeated myth was “there is no consensus” (Elsasser & Dunlap, 2012). Even as the scientific consensus continues to strengthen, conservative think tanks persist in denying the high level of agreement (Boussallis & Coan, 2015).

The public are further misinformed by the very nature of media coverage of climate change: the tendency of some media outlets historically to provide “balanced” coverage of issues even in the absence of a balance of evidence (rather than opinion) has resulted in disproportionate weight being given to a small minority of contrarian voices who dispute the scientific consensus on AGW (Boykoff & Boykoff, 2004; Painter & Ashe, 2012; Verheggen et al., 2014). In recent years, subsequent studies suggest that the mainstream U.S. press has overwhelmingly emphasized consensus views on climate science (Boykoff, 2007; Nisbet, 2011), yet a strong emphasis on false balance remains at Fox News and News Corp-owned newspapers worldwide (Feldman, Maibach, Roser-Renouf, & Leiserowitz, 2011; McKnight, 2010). Such falsely-balanced articles and news presentations have been observed to lower the perceived risk of climate change and the perceived scientific consensus (Kortenkamp & Basten, 2015; Malka et al., 2009; McCright, Charters, Dentzman, & Dietz, 2015).

Perceived consensus as a gateway belief

Why have opponents of climate action expended so much effort on casting doubt on the scientific consensus? The deliberation behind this strategy is articulated in a 2002 memo from a political strategist, Frank Luntz, who advised Republican politicians that the way to lower public support for climate policies was to cast doubt on the consensus (Luntz, 2002):

> *"Voters believe that there is no consensus about global warming in the scientific community. Should the public come to believe that the scientific issues are settled, their views about global warming will change accordingly. Therefore, you need to continue to make the lack of scientific certainty a primary issue in the debate."*

Luntz's market research has been borne out by subsequent psychological research. Several studies have found that perceived consensus about AGW is an important "gateway belief," that in turn influences a number of other beliefs and attitudes about climate change (Ding et al., 2011; McCright et al., 2013; Stenhouse et al., 2013; Aklin & Urpelainen 2014; Lewandowsky et al., 2013; van der Linden et al., 2015). A survey of American Meteorological Society members found that perceived consensus was the strongest predictor of global warming views, followed by political ideology (Stenhouse et al., 2014). Among Republicans, perceived consensus is the strongest predictor of belief in global warming (Rolfe-Redding et al., 2012). When people understand that climate scientists agree on AGW, they are more likely to accept that global warming is happening, that humans are causing global warming, that the impacts are serious and importantly, more likely to support policies to mitigate climate change.

Thus, casting doubt on consensus has the effect of decreasing acceptance of climate change and reducing support for climate policy. In fact, an experiment testing the relative efficacy of a number of misinformation strategies that make use of various climate myths found that the most potent strategy for lowering acceptance of climate change involved casting doubt on the scientific consensus on AGW (van der Linden et al., in revision). The fact that the most potent climate myth is one that undermines the scientific consensus underscores the important role of perceived consensus as a gateway belief.

The misinformation campaign targeting scientific consensus has been effective. Numerous surveys indicate that the public in many countries believe that there is significant disagreement among climate scientists about whether humans are causing global warming (Kohut et al., 2009). Only around one in ten Americans correctly estimate that more than 90% of climate scientists agree that humans are causing global warming (Leiserowitz et al., 2015). Similarly, only 11% of the public in the United Kingdom are aware that nearly all scientists agree with the consensus (Comres, 2014) and a survey of fifteen countries found the perceived consensus to be lower than the actual consensus across the board (University of Maryland, 2009).

The gap between the public perception of the consensus and the actual 97% consensus is a barrier delaying support for mitigation policies or, borrowing the metaphor of Gifford (2011), a significant “dragon of inaction”. Closing the consensus gap will remove a pivotal roadblock delaying climate action.

The efficacy of consensus messaging

The role of perceived consensus as a gateway belief underscores the importance that scientists set the record straight by communicating the high level of agreement among climate scientists (Maibach, Myers, & Leiserowitz, 2014). Communicating the 97% consensus has been observed to significantly increase perceived consensus (Kotcher et al., 2014; Cook & Lewandowsky, in press) and increase acceptance of AGW (Bolsen et al., 2014; Lewandowsky et al., 2013). In another domain, communicating the consensus about the safety of vaccination increases public support for vaccines (van der Linden, Clarke, & Maibach, 2015). Consensus messaging about climate change also has a neutralising effect on worldview, causing a stronger increase in climate acceptance among conservatives (Kotcher et al., 2014; Lewandowsky et al., 2013) although there are mixed results in this area, with one study finding polarization in response to consensus messaging among U.S. (but not Australian) participants (Cook & Lewandowsky, in press).

Different methods of communicating scientific consensus have been tested experimentally. Amongst a range of textual variations (for example, “97%,” “9 out of 10,” or “97 out of 100”), the most effective articulation of consensus was the phrase “[b]ased on the evidence, 97% of climate scientists have concluded that human-caused climate change is happening” (Maibach, Leiserowitz, & Gould, 2013). The pie chart form of communication shown in Figure 4 has been found to be one of the most effective visual communication methods in influencing perceptions that climate change is human-caused, will be harmful and that it should be addressed, especially among conservatives (van der Linden, Leiserowitz, Feinberg, & Maibach, 2014).

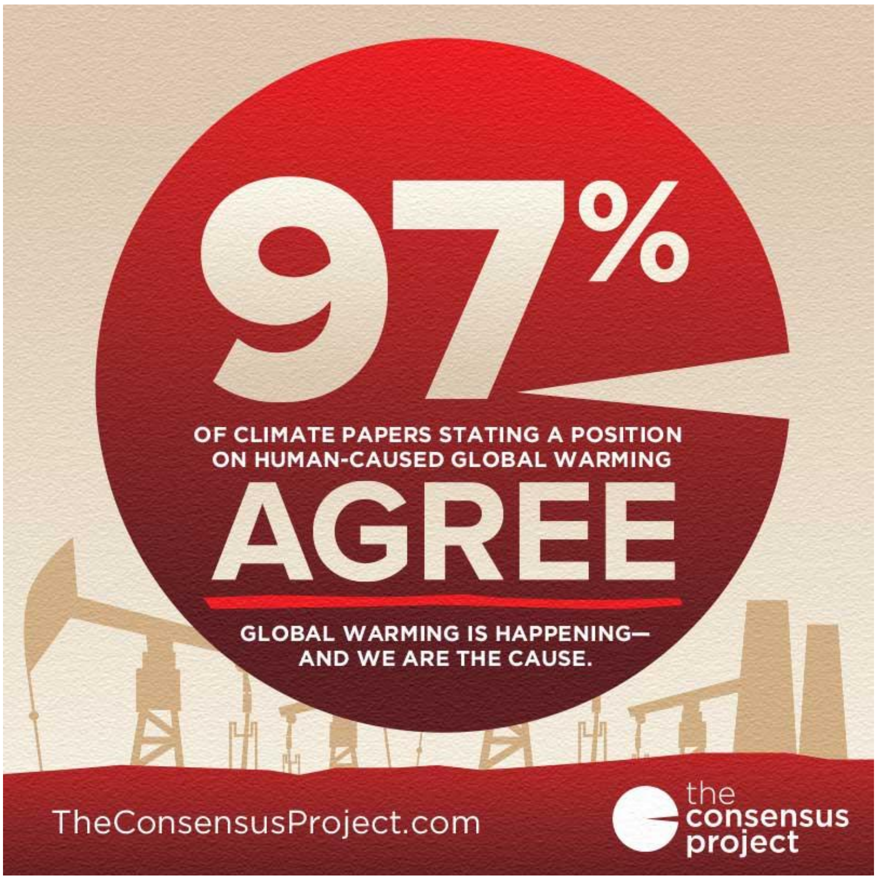

Figure 4: Communicating the 97% consensus using a pie-chart is an effective method of increasing acceptance of AGW. This infographic was created by SJI Associates for the website theconsensusproject.com. Note that while this pie-chart from theconsensusproject.com referred to the 97% consensus among climate papers, the pie-charts used in Maibach, Leiserowitz, & Gould (2013) referred to the 97% consensus among climate scientists.

Objections to consensus messaging

The publication and subsequent public interest in the 97% consensus found in Cook et al. (2013) has provoked an ongoing scholarly debate into the efficacy of consensus messaging. Such discourse is a valuable part of the scientific process, potentially leading to improved understanding of the psychology of consensus and an increased emphasis on evidence-based science communication.

One objection is that consensus messaging is an argument from authority, where "the credibility and authority of climate science is invoked as a means of persuasion" (Pearce et al., 2015, pp6). This argument highlights one potential limitation of appealing to expert opinion, which may come at the expense of educational interventions that increase critical thought and climate literacy. For example, an alternative approach of explaining the mechanism of the greenhouse effect has been observed to increase acceptance of climate change (Ranney and Clark, 2016). Similarly, increased climate literacy has been associated with increased levels of concern about climate change (Bedford, 2015).

However, the fallacy of argument from authority is bypassed in Maibach, Leiserowitz, and Gould (2013), which found that an effective version of consensus messaging emphasised the evidential foundation on which the consensus is based on. In this context, it is important that communicators understand the purpose of communicating the scientific consensus, which is not put forward as "proof" of human-caused global warming. Rather, the case for consensus messaging is based on psychological research into how people think about complex scientific issues such as climate change (van der Linden et al., 2015). In these situations, people rely on expert opinion as a heuristic, or mental shortcut, to inform their views (Petty, 1999). For example, van der Linden et al. (2014) found that using a familiar metaphor for consensus (i.e., "*If 97% of doctors concluded that your child is sick, would you believe them? 97% of climate scientists have concluded that human-caused climate change is happening.*") was effective in increasing understanding of the scientific consensus. Communication of the state of expert opinion is a reflection of the psychological reality that the lay public do not necessarily process evidence in the same manner or to the same depth as scientists.

In a second critique, Pearce et al. (2015, pp6) argue that "attempts to substitute climate science for climate politics merely prolong the debate over whether or not the science is 'sound'" (p. 6). This argues that when policy is based on scientific evidence, then science becomes a target for policy opponents. For example, the impact of the 2009 'Climategate' incident, where climate scientists' emails were stolen and published online, proved a temporary distraction from efforts to communicate climate science prior to the international climate negotiations in Copenhagen (Anderegg and Goldsmith, 2014).

A counter-argument is that the purpose of consensus messaging is precisely to defend against attempts by opponents of climate policy to cast doubt on the science, which has the purpose of distracting public discourse away from a focus on climate solutions (as was recommended in Luntz, 2002). Consensus messaging is one response to this tactic, with the aim of refocusing public discourse onto the topic of appropriate solutions to AGW. Were scientists to cease communicating the consensus, thus allowing the misinformation campaign targeting perceived consensus to continue unopposed, psychological research into the impact of misinformation (McCright et al., 2016; van der Linden et al., in revision) indicates that public confusion about the scientific understanding of AGW would deepen and delay further discussion of solutions.

Further, Pearce et al. (2015) argue that consensus messaging restricts the scope of public discussion to topics of settled science, instead suggesting celebration of areas of disagreement in climate science, using "dialogue which is inclusive of human values" (p. 6). Similarly, Hulme

(2015) argues that because of uncertainties in future impacts, “[t]he scientific consensus on climate change thus becomes unhelpfully limiting” (p. 895). Focusing on the topic of the human role in influencing the climate system runs the “[danger] of elevating climate as a predictor of future social and ecological change without appreciating the deep contingency of these changes” Hulme argues (p. 895). These concerns over what is considered “climate reductionism” reflect the philosophy that overcoming denial is achieved by exploring a more diverse and inclusive range of policy options, and by employing messengers representing a wider range of social backgrounds (Nisbet, 2014).

A counter-argument is that consensus messaging does not preclude communicating broader policy discussion, such as risk management frames, which emphasize consideration of future uncertainties. On the contrary, the two frames (consensus and risk management) are complementary. A potentially fruitful approach is to use the scientific consensus as a pivot to issues of legitimate disagreement regarding risk assessment or policy discussion. As argued by Corner, Lewandowsky, Phillips and Roberts (2015, page 6), “uncertainty at the frontiers of science should not prevent focusing on the ‘knowns’, in order to establish a common understanding with your audience.” Scientific uncertainty can be exploited to inhibit policy discussion (Freudenburg, Gramling, & Davidson, 2008), necessitating that science communicators strike a balance between communicating uncertainty and consensus.

Another objection to consensus messaging is the assertion that the “public understanding of the climate issue has moved on” since the “pre-2009 world of climate change discourse” (Hulme, 2013). Along these lines, Kahan (2016) argues that “people with opposing cultural outlooks overwhelmingly *agree* about what “climate scientists think” on numerous specific propositions relating to the causes and consequences of human-caused climate change.” In other words, the objection is that consensus messaging is unnecessary because the public (both conservatives and liberals) are already aware of the scientific consensus.

However, nationally representative surveys have found that public understanding of scientific consensus is low (Cook & Lewandowsky, 2016; Leiserowitz et al., 2015; van der Linden et al., 2016). The difference in perceived consensus varies significantly across political affiliation with only 5% of conservatives correctly understanding that the scientific consensus is above 90%, compared to 25% of liberals (Leiserowitz et al., 2015). Low perceived consensus is even found among U.S. science teachers, which has the consequence of minority contrarian views being taught to students (Plutzer et al., 2016).

Conversely, Kahan (2015) argues that the lack of a dramatic shift in public perception of consensus over a period when a number of consensus studies have been published (e.g., Oreskes, 2004; Doran & Zimmermann, 2009; Anderegg et al., 2010; Cook et al., 2013; Verheggen et al. 2014) implies that consensus messaging is ineffective. Similarly, Anderegg (2010) argues that quantifying scientific agreement falls short of spurring political action. To explain this stasis hypothesis, Kahan cites research finding that people process evidence in a biased fashion, according to cultural values (Kahan et al., 2011). Consequently, Kahan argues that consensus messaging results in increased acceptance of climate change among liberals as well as decreased acceptance of climate change among conservatives, with no significant net change in acceptance.

However, in relation to Kahan's claims of polarization, there are contradictory research findings. Lewandowsky et al. (2013), Kotcher et al. (2014) and van der Linden (2016) find that consensus messaging has a neutralising effect, with conservatives showing a greater increase in acceptance of climate change relative to liberals. In particular, van der Linden (2016) comprehensively rules out the polarization hypothesis using a variety of measures of cultural values and social identification, such as a conservative-liberal scale, Fox News viewing habits, prior attitudes towards climate change and social norm indicators. Cook and Lewandowsky (2016) also find that consensus messaging is neutralising for Australian participants, although it has a polarizing effect for U.S. participants. But even in this case, negative effects only occurred for a small proportion of the population, with the overall effect on perceived consensus being positive.

Other research indicates that climate information need not be polarising. Ranney et al. (2015) found that explaining the mechanism causing global warming (the greenhouse effect) or communicating seven climate statistics (i.e., the 97% consensus or 40% reduction in Arctic sea ice) increased acceptance of global warming across the political spectrum, with no observed polarization. Fernbach, Rogers, Fox, and Sloman (2013) found that asking people to provide a mechanistic explanation for global warming resulted in more moderated attitudes, indicating that deeper engagement with the climate issue can reduce polarization. Similarly, climate literacy measured by correctly identifying activities that cause an increase in greenhouse gases (Guy, Kashima, Walker, & O'Neill, 2014), or by true/false questions regarding the greenhouse effect, sea level rise and climate/weather (Bedford, 2015) has been associated with a weaker relationship between individualistic ideology and acceptance of climate change.

While cultural cognition plays a significant role in informing climate attitudes, it is not the only factor influencing climate perceptions and attitudes. Cook and Lewandowsky (2016) measured perceived consensus as a function of free market support, a belief that is a key dimension of political ideology. Figure 6 shows the strong influence of ideology, but even for participants with low free-market support, who possess no cultural reason to reject climate change, there is still a significant gap between perceived consensus and the actual 97% consensus. This indicates that a significant contribution to the consensus gap is either a deficit of information, and/or a surplus of misinformation.

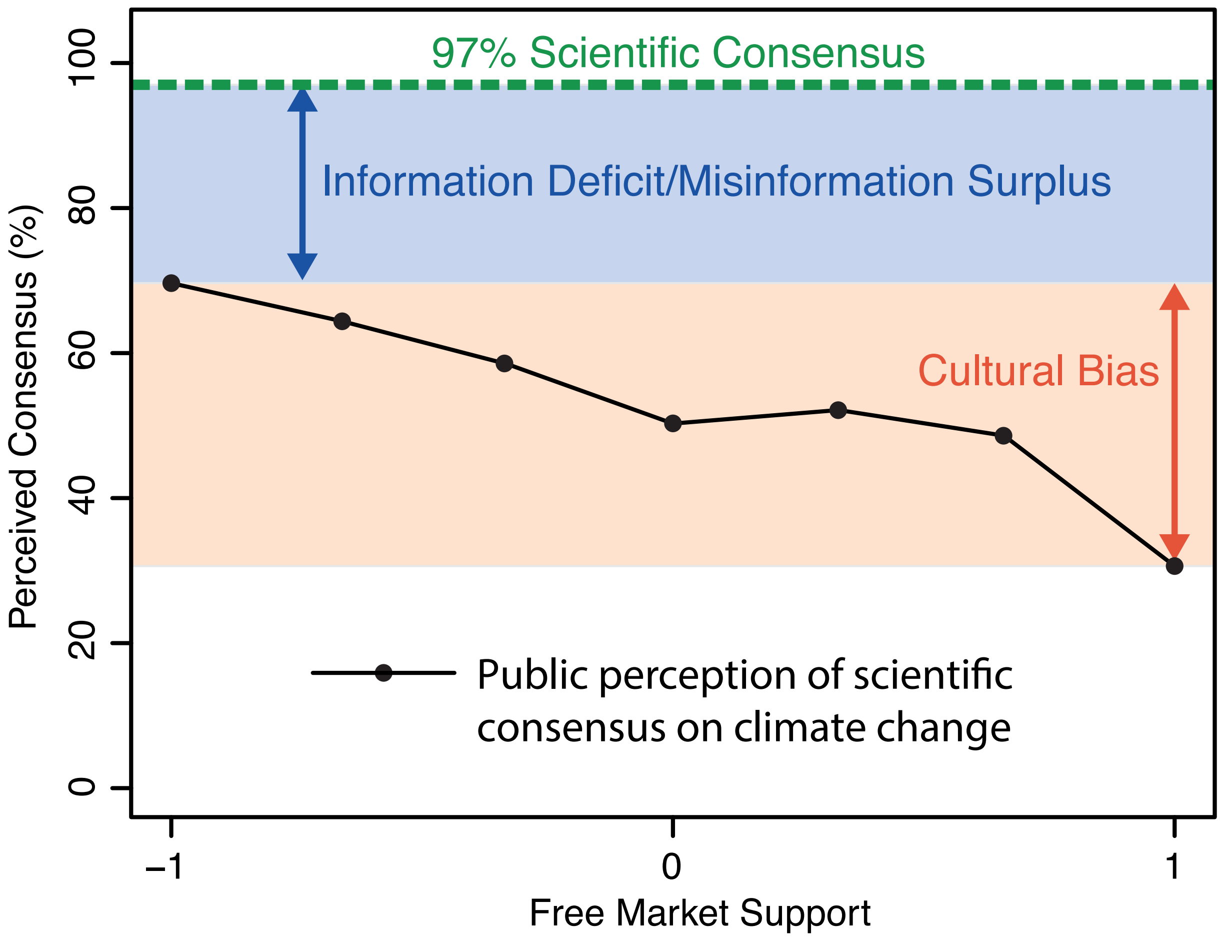

Figure 5: Perception of scientific consensus about AGW versus free-market support (plotted from data in Cook & Lewandowsky, 2015).

Further, there is an apparent conflict between Kahan's claim of the impotence of consensus messaging and the replicated experimental findings of the efficacy of consensus messaging. To reconcile the two sets of findings, Kahan (2015) and Pearce et al. (2015) argue that consensus messaging studies lack “external validity”; that is, they fail to simulate real-world conditions. There is a degree of merit to this argument. As well as accurate information about the scientific consensus, the public are also exposed to misinformation casting doubt on the consensus. An "externally valid" experiment should simulate real-world conditions where accurate and misinformation co-exist.

A recent study has experimentally tested the impact of counter-messages, showing participants information about the 97% consensus, as well as misinformation about an alleged 31,000 dissenting scientists, finding no significant change in perceived consensus (van der Linden, in revision). The finding that the positive effect of accurate information can be undone by misinformation has also been replicated by McCright et al. (2016), which found that the promising frames about climate change were partially neutralised by misinformation. Given the persistent generation of misinformation about the consensus over the past few decades (Boussalis and Coan, 2016; Elsasser and Dunlap, 2012; Oreskes & Conway, 2011), this offers a cogent explanation of why public perception of consensus has not shifted appreciably over the last decade.

The issue of consensus messaging therefore cannot be understood adequately without including the misinformation campaign that seeks to confuse the public about the level of scientific agreement on AGW. Scientists and climate communicators need to address the influence of climate science denial in a manner informed by the social science research investigating how to neutralise the influence of misinformation.

Effective refutation of misinformation

While the generation of misinformation is a persistent problem, compounding the issue is the fact that misconceptions are also psychologically difficult to dislodge (for a review, see Lewandowsky, Ecker, Seifert, Schwarz, & Cook, 2012). Misconceptions continue to influence people's reasoning after being retracted or corrected, even when people demonstrably understand, believe, and later remember the retraction (Ecker, Lewandowsky, & Tang, 2010). The persistence of corrected information in people's reasoning is known as the Continued Influence Effect (Johnson & Seifert, 1994). For example, if an initial assumption about a person (e.g., that they committed a crime) later turns out to be incorrect, the initial invalid assumption will still affect people's judgements about the person and their evaluation of the criminal incident (Ecker, Lewandowsky, Fenton, & Martin, 2014; Ecker, Lewandowsky, Chang, & Pillai, 2014).

Why does misinformation continue to influence people even after it has been retracted? People build mental models of how the world works and if an important part of that model is removed (i.e., by a retraction), the correction leaves behind a gap in that mental model. People prefer a complete model to an incomplete model, even when the complete model may contain some invalid elements. Consequently, when queried people continue to rely on the misinformation rather than tolerate a gap in their understanding (Ecker et al., 2010; Lewandowsky et al., 2012).

It follows that an effective way of reducing the continued influence effect is to fill the gap created by a retracted myth with a factual alternative (Johnson & Seifert, 1994). An instructive example is a court case where a suspect is exonerated by providing an alternative suspect. A factual alternative needs to explain the causal qualities of the retracted myth (Seifert, 2002). Ideally, the factual alternative should be less complicated and more fluent than the misinformation it dislodges (Chater & Vitanyi, 2003; Schwarz, Newman, & Leach, in press). Lombrozo (2007) found that simple explanations are judged more likely to be true than more complex explanations. Schwarz et al. (2007) also found that providing too many counterarguments can potentially backfire, strengthening initial conceptions. The tension between satisfying causal requirements and the need for simplicity is perhaps encapsulated in Einstein's famous advice on scientific explanations: "Everything should be made as simple as possible but not simpler."

The cognitive research into the qualities and implementation of refutations is succinctly summarised by Heath and Heath (2007) who recommend that communicators should "fight sticky ideas with stickier ideas" (p. 284). Sticky ideas are messages that are simple, compelling and memorable. One example of a sticky message is a narrative such as a murder mystery that arouses curiosity and then satisfies it. The way to achieve this is by opening a gap in a person's knowledge, then filling that gap with new information (Loewenstein, 1994). This approach lends itself to refutations which create a gap in a person's mental model, then fill that gap with a factual alternative. The implication is that refutation of misinformation need not be seen merely as a necessary evil. If implemented properly, a refutation offers science communicators the opportunity to communicate the science in a compelling, sticky manner. Figure 6 shows how a sticky factual alternative fits into the structure of an effective refutation.

An example of sticky messaging in the context of climate communication can be found at the website 4hiroshimas.com, which was created to refute the myth that global warming had stopped since 1998. Since that year, the planet has continued to accumulate heat at a rate of over 250 trillion joules per second (Nuccitelli, Way, Painting, Church & Cook, 2012). To communicate this statistical summary of the planetary energy imbalance in a simpler and more concrete manner, it was expressed as the equivalent of four atomic bombs worth of heat every second. This information was made available as an animated widget for embedding in other blogs and website.

While the most important element of a debunking is strong emphasis on a “sticky” factual alternative, it is still often necessary to explicitly refute the misinformation. One risk in mentioning the myth is that it makes people more familiar with the misinformation – the more familiar people are with a piece of information, the more likely they are to think that it’s true (Schwarz et al., 2007). However, this risk can be mitigated by explicitly warning people that you are about to mention the myth (Ecker et al., 2010; Jou & Foreman, 2007; Schul, 1993). A pre-emptive warning puts the recipient “cognitively on-guard,” reducing the chance that they will be influenced by the misinformation. Figure 6 shows how the explicit mention of misinformation should come only after the factual alternative and an explicit warning about the myth.

Presenting both the factual alternative and the myth creates a conflict - raising the question of how the two conflicting pieces of information can co-exist. Another quality of an effective retraction is explanation of how or why the misinformation was generated in the first place, and/or the motivations behind the misinformation (Lewandowsky, Stritzke, Oberauer, & Morales, 2005). Explaining how misinformation came about enables recipients to reconcile the contradiction between the misinformation and the correction (Seifert, 2002). A refutation answers this question – filling the "gap" created by the conflict – by explaining how the misinformation arose or the techniques the misinformer uses to distort the facts. As illustrated in Figure 6, a useful framework for explaining the techniques of denial are the five characteristics of science denial: fake experts, logical fallacies, impossible expectations, cherry picking and conspiracy theories (Diethelm & McKee, 2009).

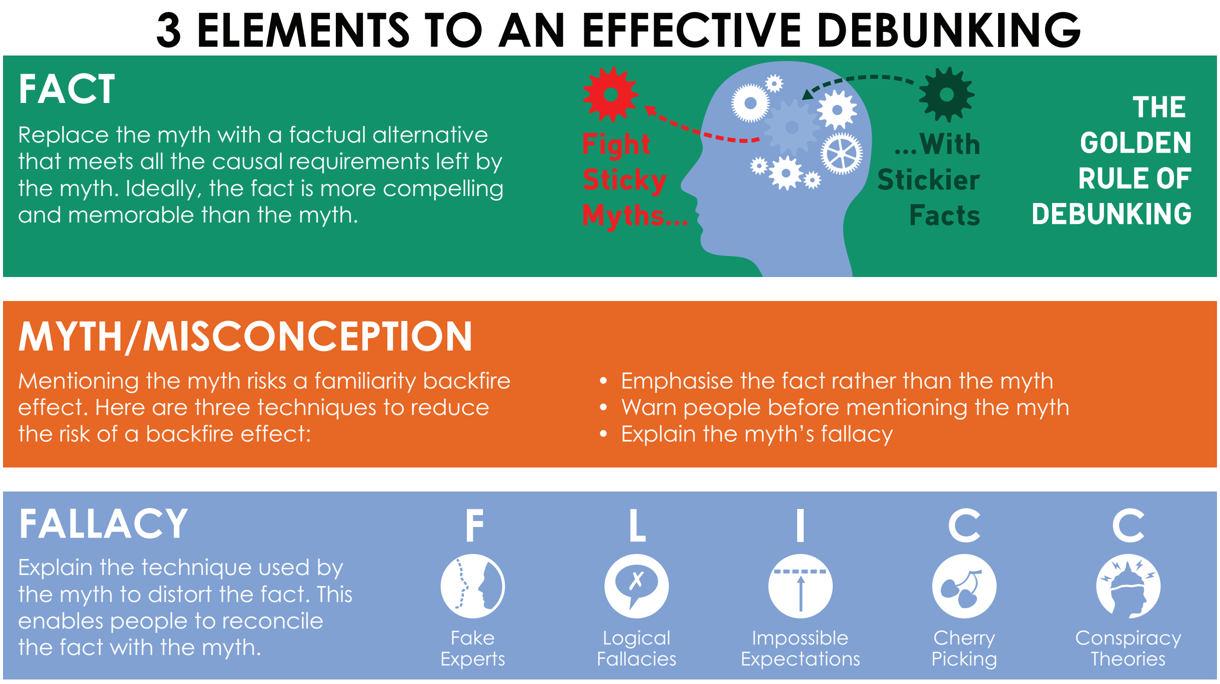

Figure 6: Recommended structure for a refutation: Fact-Myth-Fallacy.

Additionally, graphics can play a powerful role in refutations. When a refutation conflicts with a person's pre-existing beliefs, they will seize on ambiguities in the text to construct an alternative explanation. Clear, unambiguous graphics that specify and/or quantify the communicated evidence provide less opportunity for misinterpretation and counter-arguing, as well as add fluency to a rebuttal (Schwarz, Newman, & Leach, in press). For example, Republicans showed a greater acceptance of global warming when shown a graph of temperature trends, compared to a content-equivalent textual description of global warming (Nyhan & Reifler, 2012).

These recommended best-practices for debunking can help reduce the influence of misinformation that has already been received by recipients. However, trying to reduce the influence of misinformation once it is lodged in people's minds is still a difficult exercise (Lewandowsky et al., 2012). Another promising avenue of approach that circumvents this difficulty is pre-emptively refuting misinformation *before* it is received by recipients (known as "prebunking"), which has been observed to be more effective in reducing the influence of misinformation (Bolsen & Druckman, 2015).

Inoculation: prebunking is the new debunking

Research indicates that it is more efficient to prevent misinformation from taking root in the first place, rather than trying to undo the damage retroactively. For example, people who were suspicious of the U.S. government's motives during the Iraq war were less vulnerable to misinformation about the war (Lewandowsky et al., 2005). Similarly, people's pre-existing attitudes towards a company influenced how they interpreted charitable behaviour by that company, with charity by a company with a bad reputation being seen as motivated by self-interest (Bae & Cameron, 2006).

Consequently, an alternative response to retroactively refuting misinformation is to pre-emptively neutralise the misinformation (prebunking). This approach is informed by inoculation theory (Compton, 2013; McGuire & Papageorgis, 1961), which applies the metaphor of vaccination to knowledge. Just as exposing people to a weak form of a virus builds resistance to a future encounter with the virus, in the same way exposing people to a refuted form of a myth conveys resistance to persuasive misinformation. This occurs by equipping people with counter-arguments that expose the logical fallacies contained in the misinforming arguments. Consequently, they are better able to recognise and dismiss flawed or misleading arguments. Inoculating messages have been observed to more effectively convey resistance to misinformation compared to "straight science" messages that don't explicitly address misinformation (Banas & Rains, 2010).

To illustrate, Bolsen and Druckman (2015) found that pre-emptive warnings about politicizing science can counteract the effects of politicization. By politicization, they mean "emphasizing the inherent uncertainty of science to cast doubt on the existence of scientific consensus" (p. 747) which is to be distinguished from misinformation which is false information. Subtle distinctions aside, this research was of particular note as it compared the relative efficacy of prebunking versus debunking (refuting the myth after the misinformation), and found that prebunking was more effective in reducing the influence of the misinformation.

An inoculating message requires two elements. First, it should explicitly warn of the threat of misinformation. Second, it should contain refutations of the arguments adopted by the misinformation. Using misinformation about the scientific consensus as an example, an inoculating message could warn of the existence of arguments casting doubt on the scientific consensus on human-caused global warming, then explain the techniques used by these arguments (such as the fallacy of "fake experts"). Armed with the counter-arguments enabling one to perceive the misleading nature of misinformation, people acquire resistance and are less vulnerable to being persuaded by the misinformation.

Two studies have applied the approach of inoculation to climate change, and in particular, the issue of scientific consensus. van der Linden et al. (in revision) tested the influence of misinformation about the consensus, using the "31,000 scientists" argument from the Global Warming Petition Project (http://www.petitionproject.org/). This website features a petition listing over 31,000 signatories with a science degree or higher, who have indicated agreement with the myth that human activity is not causing disruption of the Earth's climate – a statement that conflicts with the consensus position that humans have caused most of global warming (Qin et al., 2014). One group who viewed the misinformation with no other information showed a 10% reduction in perceived consensus – demonstrating that casting doubt on the consensus does have an impact on people's perceptions of climate change. Those that were informed of the 97% consensus as well as the misinformation showed no significant change in perceived consensus. This indicates that misinformation has the potential to cancel out the positive influence of consensus messaging, and explains why public perception of consensus has shown little shift over the past decade. Another group were informed of the 97% consensus, then given an inoculating message that explained the technique of the misinformation, before receiving the misinformation. This intervention had the effect of significantly increasing perceived consensus, indicating that the inoculation largely neutralised the influence of the misinformation.

A second study also presented an inoculating message before showing students misinformation from the Global Warming Petition Project (Cook, Lewandowsky, & Ecker, 2015). In this study, the misinformation-only group showed a decrease in perceived consensus. The inoculation message did not mention the Petition Project specifically, but rather described in general terms how the technique of "fake experts" is used to create public doubt about an issue (using tobacco as a specific example). The inoculation was completely effective in neutralising the misinformation, with no change in perceived consensus for the inoculation group. This indicates that inoculations that refute denialist arguments in general terms could have broad impact, potentially neutralising other myths that use the same misleading technique.

The research into inoculation offers promising avenues for science communicators. Inoculation interventions seem to shift people from a shallow, heuristic mode of thinking to a more considered approach to information processing (Kahneman, 2003). This idea is consistent with the suggestion that science communicators should not just address the information deficit – they must also address the "wisdom deficit," where "cognitively sophisticated educators can provide the tools that help the public better evaluate the evidence" (Clark, Ranney, & Felipe, 2013, p. 2071). Clark et al. (2013) experimentally test mechanistic explanations of the greenhouse effect to demonstrate the efficacy of promoting a richer understanding of the concept, while also referencing the communication tools and techniques listed in Lewandowsky et al. (2012) for correcting misinformation. Examples of communication techniques include providing factual alternatives to displace refuted myths, fostering healthy scepticism about misinformation sources and framing evidence in a world-view affirming manner.

Misconception-based learning: inoculation in an educational context

The notion that inoculation stimulates people to engage at a deeper level with scientific information also resonates with a line of educational research known as misconception-based learning. This research finds that teaching science by refuting misconceptions about the science stimulates more cognitive effort and higher engagement with the content, resulting in greater learning gains compared to lessons that do not address misconceptions (Muller, Bewes, Sharma, & Reimann, 2007; Muller, Sharma, & Reimann, 2008).

Correcting scientific misconceptions is an important part of science education. As Osborne (2010) aptly put it, “[c]omprehending why ideas are wrong matters as much as understanding why other ideas might be right”. The approach of addressing misconceptions in an educational context has been referred to in various ways, such as misconception-based learning (McCuin, Hayhoe, & Hayhoe, 2014), agnotology-based learning (Bedford, 2010) or refutational text (Tippett, 2010).

Misconception-based learning involves lessons that directly address and refute misconceptions as well as explain factual information, in contrast to standard lessons that teach the facts without explicitly addressing misconceptions. For example, one myth regarding the carbon cycle is that anthropogenic carbon dioxide (CO2) emissions are inconsequential because they are small in magnitude compared to natural CO_2 emissions. A misconception-based learning approach might explain the natural balance inherent in the carbon cycle, with natural CO_2 emissions roughly balanced by natural CO_2 absorptions, and how anthropogenic CO_2 emissions have upset the natural balance. Thus the technique employed by the myth is "cherry picking", failing to consider the role of natural CO_2 absorptions in the carbon cycle. Misconception-based learning has been shown in a number of studies to be one of the most effective means of reducing misconceptions (Muller et al., 2008; Kowalski & Taylor, 2009; Tippett et al., 2010). This educational approach also achieves long-term conceptual change, lasting from weeks to several months (Guzzetti, Snyder, Glass, & Gamas, 1993).

Part of the power of misconception-based learning is that it not only imparts content concepts, it also addresses epistemological concepts, exploring how knowledge is produced. While both content and epistemology are necessary to bring about lasting conceptual change, education has tended to focus on the former due to the difficult challenge of teaching the latter (Posner et al., 1982). Misconception-based learning increases students' argumentative skills (Kuhn & Crowell, 2011) and encourages students to assess evidence, thus raising critical thinking (Berland & Reiser, 2008; Ecker, Swire, & Lewandowsky, 2014; Kuhn & Crowell, 2011). Students are more interested in refutational texts compared to traditional textbooks (Mason, Gava, & Boldrin, 2008).

Just as the structure of debunking lends itself to compelling, "sticky" science communication, misconception-based learning offers a powerful method of science education.

One might thus argue (taking a glass-half-full perspective) that the existence of misinformation about climate change presents an educational opportunity.

The opportunities inherent in misconception-based learning are already being applied in the classroom. One negative influence on climate literacy levels is the “teach the controversy” approach, where both sides of the scientific debate are presented on issues such as climate change and evolution. A survey of U.S. science teachers found that 31% who taught climate change were emphasizing both the scientific consensus on human-caused global warming and that many scientists believe global warming was due to natural causes (Plutzer et al., 2016). However, teachers have also re-purposed the “teach the controversy” framing in order to educate middle and high school students on climate change (Colston & Vadjunec, 2015). Misconception-based learning is also being applied at tertiary level, with Bedford (2010) and Cook, Bedford, and Mandia (2014) describing classroom-based case studies in misconception-based learning. The case study described in Bedford (2010) had students in a university in northern Utah, USA assess the veracity of Michael Crichton’s book *State of Fear* (Crichton, 2004). This fictional book features a group of eco-terrorists fabricating a series of disasters to be blamed on global warming, with Crichton seamlessly weaving misinformation that casts doubt on climate science into the book’s narrative. Students were instructed to engage with the arguments in the book and critically argue their own position. Another case study documented in Cook, Bedford, and Mandia (2014), based in a New York community college, involved a research-paper assignment requiring students to refute a climate myth of their choosing, taken from SkepticalScience.com, a website that refutes climate misinformation with peer-reviewed scientific research. Students were instructed to conform to the structure of an effective debunking according to psychological research outlined in Section 5; also summarised in *The Debunking Handbook* (Cook & Lewandowsky, 2011).

Lastly, a University of Queensland Massive Open Online Course, or MOOC, *Making Sense of Climate Science Denial* (Denial101x), implemented the approach of misconception-based learning, reaching over 21,000 students from over 160 countries (Cook et al., 2015b). MOOCs are particularly powerful tools as they allow educators to reach out to potentially hundreds of thousands of students, using interactive online systems and community-based forums to engage and educate students. The MOOC platform also allows comprehensive collection of data on student behaviour and learning gains as they navigate through the course. This data enables instructors to identify strengths and weaknesses in online material, enabling iterative development increasing the efficacy of their courses.

Conclusion

Climate science denial and misinformation has a damaging impact on public perceptions of climate change and climate literacy levels, with a subsequent decreased support for mitigation policies. Consequently, it is important that scientists, communicators and educators adopt an evidence-based response to science denial. Psychological research offers a number of guidelines in developing refutations that effectively reduce the influence of misinformation.

Nevertheless, there remain many challenges in further exploring the psychology of misinformation and refining practical interventions (see Cook, Ecker & Lewandowsky, 2015 for an overview of anticipated future lines of research). Better understanding of the confounding role of worldview in influencing climate attitudes and amplifying the impact of misinformation is one of the greatest challenges for researchers.

While a growing body of experimental evidence supports the efficacy of consensus messaging, scholarly debate over consensus messaging is expected to continue. One possible area of investigation is the effectiveness of combining consensus messaging with policy-related information or different mitigation-related technologies. Another area of investigation is the relative efficacy of consensus messaging versus other forms of scientific explanation (e.g., presentation of empirical evidence for AGW), or when paired with competing climate denial messages (e.g. McCright et al., 2016) and possible interactions between the various types of messaging.

A relatively neglected area of climate communication research is the impact of misinformation and ways to neutralise its influence. Machine learning techniques are now being used to analyse large bodies of data, gleaning insights into misinformation content and networks (see for example, Boussalis & Coan, 2016). Further investigation into practical refutation techniques is required, particularly testing the interaction of different climate messages delivered by a range of messengers to a variety of audiences. Initial research, built on decades of work on inoculation theory, have found that inoculation against climate misinformation is an effective intervention. Further investigation of this intervention type is worthy of future study, leading to the development of specific recommendations for communicators.

Similarly, while decades of research have established the efficacy of misconception-based learning, there is little empirical research into this teaching approach specific to climate change, at both secondary and tertiary level. Tippett (2010) laments the rarity of misconception-based learning material in textbooks. While such resources do exist in textbook form (Bedford & Cook, 2016) as well as online video resources (Cook et al., 2015b), practical application, empirical testing and iterative development of such educational resources is required.

In summary, psychological research indicates promising interventions in closing the consensus gap and reducing the influence of misinformation. Particularly effective are prebunkings, taking the form of inoculation against misinformation. A practical and powerful way to implement inoculation is misconception-based learning, which teaches scientific concepts by directly addressing and refuting misconceptions. Future research and practical application should further test and refine communication techniques.

Suggested Readings

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Chapter 5
Neutralising misinformation through inoculation

This chapter is presented in the format of two journal article manuscripts.

Cook, J., Lewandowsky, S., & Ecker, U. K. H. (2016, submitted). Neutralising misinformation through inoculation: Exposing misleading argumentation techniques reduces their influence.

Lewandowsky, S., Cook, J., & Lloyd, E. A. (2016, submitted). The `Alice in Wonderland' Mechanics of the Rejection of (Climate) Science: Simulating Coherence by Conspiracism.

Foreword

As described in Chapter 3, Cook and Lewandowsky (2016) found that when informed about a scientific consensus, American participants who were strong supporters of unregulated free markets responded by decreasing their acceptance of global warming. This response was driven by an active distrust of climate scientists – while not accepting AGW, they *expected* climate scientists to falsify evidence supporting AGW. This pattern of thinking is consistent with other research observing an association between the rejection of AGW and conspiratorial thinking (Lewandowsky, Gignac, & Oberauer, 2013; Lewandowsky, Oberauer, & Gignac, 2013; Smith & Leiserowitz, 2012).

The conspiratorial nature of climate science denial carries with it a number of characteristics, two of which we will focus on. First, conspiratorial thinking is self-sealing by nature (Lewandowsky, Cook, Oberauer, Brophy, Lloyd, & Marriott, 2015). This means that any evidence purporting to falsify a conspiracy is viewed by the conspiracy theorist as further evidence *supporting* the existence of the conspiracy. The self-sealing nature of conspiratorial thinking implies that climate science denial is likely to persist despite the accumulating body of evidence for anthropogenic global warming. This also means the generation of misinformation casting doubt on climate science is also expected to persist. This has been observed in an analysis of conservative think-tank publications, with arguments against climate science on the increase since 2009 (Boussalis & Coan, 2016).

Second, Chapter 3 found that distrust in an information source—in this case the scientists who support the scientific consensus—reduces the influence of the information, and can even cause it to backfire (Fein, McCloskey, & Tomlinson, 1997; Green &

Donahue, 2011; Marchand & Vonk, 2005). This is consistent with research that found that suspicion of the government's motives regarding the Iraq War of 2003 made people less likely to believe in misinformation about the war (Lewandowsky, Stritzke, Oberauer, & Morales, 2005). Similarly, philanthropic behaviour by disreputable corporations has been observed to backfire, being viewed as an act of self-interest (Bae & Cameron, 2006).

The potentially positive effect of suspicion implies that inducing a suspicious state by pre-emptive refutation (or "prebunking") may be an effective strategy in reducing the influence of misinformation. One line of research that explores the implementation of pre-emptive refutation of misinformation is inoculation theory (McGuire & Papageorgis, 1961). This research borrows the metaphor of inoculation from medicine and is applying it to knowledge generation. Inoculation theory proposes that exposing people to weak (i.e., refuted) versions of arguments can confer resistance when stronger versions of the argument are subsequently encountered. This communication approach may be applied in the climate domain by exposing people to weak versions of climate misinformation.

In Cook, Lewandowsky, and Ecker (2016), we tested various messages that inoculate people against misinformation before exposing them to the actual misinformation. The inoculations did not contain specific misinformation themselves, but rather explained in general terms the techniques used to distort the evidence. These generically framed inoculations were effective in neutralising the influence of subsequently presented misinformation, and were particularly effective with free-market supporters who, in the absence of inoculation, were also the most influenced by climate misinformation.

Lewandowsky, Cook, and Lloyd (2016, submitted) presents an example of an inoculating message, by examining the incoherence on display by those who oppose the scientific consensus on climate change. We examine a number of examples of mutually contradictory claims about climate science, and discuss how this incoherence is a known attribute of conspiracist ideation.

Chapters 3 and 5 outlined my research into communicating the scientific consensus and countering misinformation. This research adds to the existing research into misinformation and consensus messaging. It is important that social science researchers summarise and communicate the psychological research into science communication to the academic community, in order to raise awareness of evidence-based best-practices. I will outline my attempts to do so in Chapter 5.

Neutralising Misinformation Through Inoculation: Exposing Misleading Argumentation Techniques Reduces Their Influence

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Abstract

Misinformation undermines a well-functioning democracy. For example, public misconceptions about climate change can lead to lowered acceptance of the reality of climate change and lowered support for policies to mitigate global warming. This study experimentally explored the impact of misinformation and tested several pre-emptive interventions that were designed to reduce the influence of misinformation. We found that misinformation that confuses people about the level of scientific agreement regarding anthropogenic global warming (AGW) has a polarizing effect, with political conservatives reducing belief in AGW whereas political liberals increase their belief in AGW. Likewise, false-balance media coverage (giving contrarian views equal voice with climate scientists) has the overall effect of lowering perceived consensus and interacts with political ideology, with greater reduction in perceived consensus among conservatives. However, we found that inoculating messages that explain the technique used in the misinformation or that highlight the consensus are effective in neutralizing misinformation effects. We recommend that climate communication messages should take into account ways that scientific content can be distorted, and include pre-emptive inoculation messages.

Keywords: misinformation, inoculation, climate change, scientific consensus

Neutralising Misinformation Through Inoculation: Exposing Misleading Argumentation Techniques Reduces Their Influence

Misinformation, that is, information that people might accept as being true despite it being false, can have significant societal consequences. For example, denial of the scientific consensus that HIV causes AIDS led to policies estimated to have contributed to 330,000 deaths in South Africa between 2000 and 2005 (Chigwedere, Seage, Gruskin, Lee, & Essex, 2008). In Western countries, decreased acceptance of the benefits of vaccination based on erroneous or exaggerated reports of risk has led to lower compliance, placing the population at greater risk (Smith, Ellenberg, Bell, & Rubin, 2008; Poland & Spier, 2010; Carrillo-Santisteve, & Lopalco, 2012) and likely leading to the U.S. measles outbreak in 2015 (Majumder, Cohn, Mekaru, Huston, & Brownstein, 2015).

Given the plethora of information individuals are faced with on a daily basis, it comes as no surprise that people do not and cannot assess every piece of information on its merit. Rather, heuristics—mental rules-of-thumb—are frequently applied when evaluating claims and evidence: Have I heard this before? Does it fit in with what I already know? What do relevant others think about it? As with all heuristics, this can be an effective strategy in many circumstances (cf. Richter, Schroeder, & Wöhrmann, 2009) but it is prone to bias, especially when particular myths are frequently encountered, when existing knowledge is incorrect, and/or when one's social neighborhood shares or even identifies through false beliefs. In other words, individuals do not seek and interpret information in a neutral, objective manner—rather, people tend to favor information that confirms existing beliefs, and information processing is thus subject to a confirmation bias (Johnson, Bichard, & Zhang, 2009; Nickerson, 1998). Arguably, this confirmation bias is particularly strong when the underlying belief or attitude is particularly strong, in which case counter-attitudinal evidence is frequently dismissed uncritically.

The Effects of Worldviews on the Acceptance of Evidence

The behavioral and societal consequences of misinformation underscore the need to improve our understanding of how misinformation might be corrected and its influence reduced. However, this can be a problematic exercise because misperceptions have been found to be remarkably persistent to corrections, and interventions are known to backfire if applied incorrectly. Perhaps the most pervasive backfire effect involves information that challenges people's "worldview", that is, their fundamental beliefs about how society should be structured. The worldview backfire effect refers to the fact that when corrective evidence contradicts a person's prior beliefs, their beliefs may ironically be strengthened despite the evidence (for reviews, see Ecker, Swire, & Lewandowsky, 2014; Lewandowsky, Ecker, Seifert, Schwarz, & Cook, 2012). For example, in one study, conservatives became *more* likely to believe that Iraq had weapons of mass destruction (WMDs) immediately before the war of 2003 after reading retractions clarifying that no WMDs existed (Nyhan & Reifler, 2010). Similarly, receiving information about the scientific consensus on anthropogenic global warming (AGW) can cause participants with strong support for free, unregulated markets to become *less* accepting of climate change (Cook & Lewandowsky, 2016).

As misinformation is often resistant to correction—in particular if a correction contrasts with a person's worldview—alternative avenues of dampening the impact of misinformation need to be explored. One promising approach, derived from inoculation theory (Compton, 2013; McGuire & Papageorgis, 1961; see details below), is to prepare people for potential misinformation by exposing some of the logical fallacies inherent in misleading communications. The rationale is that people so “inoculated” will be enabled to subsequently recognize flawed arguments and dismiss them as deceptive. To foreshadow briefly, in two experiments we looked at two sides of the misinformation coin: we examined the effects of misinformation on climate attitudes, and we sought to eliminate the effects of that misinformation through the exploration of various types of counter-information provided *before* exposure to the misinformation. We were particularly interested in whether our counter-information approach would be able to offset misinformation effects even when the counter-information conflicted with people’s worldview and might therefore be received critically. In both experiments, the manipulations related to the scientific consensus on climate change, focusing either on the misleading strategy to present evidence from “fake experts” (Experiment 1) or undermining the perceived consensus through demonstrating a “false balance” of evidence (Experiment 2). In the following, we first elaborate on the general effects of worldview on the acceptance of evidence, before we address the scientific consensus on climate change, and review the literature on inoculation theory.

In general, evidence is often rejected if it threatens a person’s worldview. In the case of climate science, the worldview that is threatened by the bulk of the scientific evidence is political conservatism: Accepting the evidence that human activities drive climate change inevitably means embracing behavioral change—including support of increased regulation of free markets—that sits uncomfortable with conservative values of liberty and freedom. Accordingly, climate change perceptions and attitudes have been repeatedly found to be strongly associated with political worldview (Heath & Gifford, 2006; Kahan, Jenkins-Smith, & Braman, 2011; Lewandowsky, Oberauer, & Gignac, 2013; Stenhouse, Maibach, & Cobb, 2013).

Trust in climate scientists also plays a part in shaping climate attitudes (Malka, Krosnick, & Langer, 2009). Rejection of climate change has been associated with conspiratorial thinking (Lewandowsky, Gignac, & Oberauer, 2013; Lewandowsky, Oberauer, & Gignac, 2013), with conspiratorial thoughts being the most common reaction to climate change information amongst those who reject climate science (Smith & Leiserowitz, 2012). Recently, a cognitive model based on Bayesian networks found that the potentially conspiratorial trait of ‘active distrust of scientists’ was a key component of the cognitive processes leading to the rejection of evidence (Cook & Lewandowsky, 2016).

In sum, worldview can lead people to embrace misinformation without scrutiny, and (as reviewed earlier) to also dismiss counter-attitudinal corrections, which can even backfire and further entrench misconceptions. Worldview also influences perception of scientific consensus on climate change, as well as how people respond to information about consensus.

Distortions of Scientific Consensus

Several studies have found nearly unanimous agreement among publishing climate scientists that humans are causing global warming (Anderegg et al., 2010; Doran & Zimmermann, 2009; Cook et al., 2016), and a similar pervasive consensus exists in the scientific literature (Cook et al., 2013; Oreskes, 2004). A frequently-cited figure puts the consensus at around 97% of publishing scientists and of peer-reviewed articles. However, among the general public, the perception of the scientific consensus is considerably lower, and hovers around 57-67% across studies (e.g., Cook & Lewandowsky, 2016; Leiserowitz et al., 2015). This gap between public perception and the 97% level of actual agreement is significant because perceived consensus has been identified as a “gateway belief” that influences a number of other beliefs about climate change and climate solutions (Cook & Lewandowsky, 2016; Lewandowsky, Gignac & Vaughan, 2013; van der Linden et al., 2015).

One reason why the public may be generally under-estimating the consensus is because of the prominence of political operatives and lobbyists who dissent from the consensus in public discourse. Those individuals appear to have relevant expertise but in fact they rarely do (i.e., they are ‘fake experts’; Diethelm & McKee, 2009). Another potential contributor to low perceived consensus is media coverage that gives balanced coverage of both contrarian voices and expert views (i.e. ‘false balance’ coverage). Media coverage of scientific issues has diverged from the scientific consensus on issues such as climate change (Boykoff & Boykoff, 2004; Boykoff & Mansfield, 2008; Painter, 2013) and the mythical vaccine-autism link (Clarke, 2008). False-balance media coverage has been observed to decrease public certainty about scientific issues when it comes to environmental science (Kortenkamp & Basten, 2015), the false link between vaccination and autism (Dixon & Clarke, 2013), and the health effects of pollution (Stocking & Holstein, 2009). Given the presence of potentially credible fake experts and the false balance presented by the media, what are the options available to communicators to effectively reduce the influence of misinformation?

Prebunking and Inoculation Theory

Given the difficulties associated with correcting misinformation once it has been processed (Lewandowsky et al., 2012), an alternative approach is to neutralize potential misinformation *before* it is encoded, colloquially known as “prebunking”. In a field study involving pre-existing attitudes, it was found that people who were suspicious of the U.S. government’s motives for the invasion of Iraq in 2003 were subsequently less likely to believe in retracted misinformation—information that had been explicitly identified as false—about the war

(Lewandowsky, Stritzke, Oberauer, & Morales, 2005). In other research, it has been found that pre-existing reputations of a company influence how corporate philanthropic messages are received, with a bad reputation resulting in corporate charitable behavior being seen as a self-interested activity (Bae & Cameron, 2006).

These studies indicate that pre-existing attitudes influence how people respond to information (or misinformation). Similarly, inoculation theory proposes that people can be "inoculated" against misinformation by being exposed to a refuted version of the message (McGuire & Papageorgis, 1961). Just as vaccines generate antibodies to resist future viruses, inoculating messages equip people with counterarguments that potentially convey resistance to future misinformation, even if the misinformation is congruent with pre-existing attitudes.

There are two elements to an inoculation: (1) an explicit warning of an impending threat and (2) a refutation of an anticipated argument that exposes the imminent fallacy. For example, an inoculation might include (1) a warning that there exist attempts to cast doubt on the scientific consensus regarding climate change, and (2) an explanation that one technique employed is the rhetorical use of a large group of "fake experts" to feign a lack of consensus. By exposing the fallacy, the misinformation (in this case, the feigned lack of consensus) is delivered in a "weakened" form. Thus, when people subsequently encounter a deceptive argument, the inoculation provides them with a counter-argument to immediately dismiss the misinformation.

Inoculation messages have been found to be more effective at conveying resistance to misinformation than supportive messages (i.e., messages that promote accurate information without mentioning the misinformation; Banas & Rains, 2010). Inoculation messages are also useful in behavior-change interventions, with participants responding positively (compared to a control group) to inoculations against arguments justifying alcohol consumption (Duryea, 1983), the threat of peer-pressure leading to smoking initiation (Pfau, Bockern, & Kang, 1992), and pro-sugar arguments from soda companies (Niederdeppe, Gollust, & Barry, 2014). Inoculation can reduce the influence of conspiracy theories by increasing the degree of scepticism towards conspiratorial claims (Banas & Miller, 2013), and has been shown to convey resistance to misinformation regarding agricultural biotechnology (Wood, 2007). Inoculation is effective with people possessing different pre-existing attitudes—a situation particularly relevant to the climate change issue (Wood, 2007). Also of relevance, given that individualism and free-market support are strong drivers of climate attitudes, is the fact that emphasizing the dubious practices of an information source can shed light on how misinformation impinges on people's freedom to be accurately informed, thus potentially enhancing the effectiveness of inoculations among conservatives (Miller et al., 2013).

Inoculation has been tested experimentally in the context of climate change. Van der Linden et al. (2016) observed that when participants were exposed to consensus information prior to misinformation casting doubt on the consensus, there was no significant change in acceptance of climate change. This indicates that the positive effect of accurate information can be potentially undone by misinformation. The study also found that the greatest increase in AGW acceptance occurred when the consensus information was coupled with an inoculation explaining the technique employed by the misinformers, prior to receiving the misinformation.

This article addresses two research questions. First, what effect does misinformation have on climate beliefs? Second, can inoculation neutralize the influence of misinformation? We examined several ways of inoculating against climate-change-related misinformation, by explaining the techniques used to sow doubt about the science. We also extended van der Linden et al.'s (2016) study by exploring the impact of inoculation on two types of misinformation:

arguments that explicitly cast doubt on consensus and arguments that implicitly cast doubt on consensus using false-balance coverage. Experiment 1 looked at explicit misinformation that seeks to manufacture doubt about the scientific consensus by employing the 'fake experts' strategy. Experiment 2 looked at misinformation in the form of 'false balance' media coverage, which misinforms by conveying the impression of evenly balanced discourse in the scientific community regarding climate change. In both studies, the effectiveness of inoculations was compared to conditions in which misinforming messages were left uncorrected.

Experiment 1

Method

Experiment 1 tested the impact of misinformation that explicitly seeks to manufacture doubt about the scientific consensus on climate change. It also tested whether inoculating participants prior to reading misinformation was effective in neutralizing the influence of the misinformation. The experiment thus featured a 2 × 2 between-subjects design, fully crossing a misinformation intervention and an inoculation intervention, such that participants were divided into a control group (no intervention text), inoculation group (inoculation with no misinformation), misinformation group (misinformation with no inoculation) and inoculation/misinformation group (inoculation preceding misinformation). The study was approved by the Human Research Ethics Committee at the University of Western Australia, with participants indicating written consent through participation in the online survey.

Participants. Participants (*N* = 392) were a representative U.S. sample, recruited through Qualtrics.com, an online survey firm. Participants were selected based on U.S. demographic data on gender, age and income (49.2% female, average age 42 years, *SD* = 17 years)—a procedure which has been shown to reasonably approximate representativeness (Berrens et al., 2003). The time taken to complete the survey was used to eliminate outliers (*n* = 8) according to the outlier labeling rule (time duration more than 2.2 times the inter-quartile range from the 1st or 3rd quartile; Hoaglin, Iglewicz, & Tukey, 1986). Participants were randomly allocated to the four experimental conditions: control (*n* = 98), inoculation (*n* = 98), misinformation (*n* = 99) and inoculation/misinformation (*n* = 97).

Materials. The misinformation intervention consisted of text taken verbatim from the Global Warming Petition Project website (http://www.petitionproject.org/). This website, run by the so-called Oregon Institute of Science and Medicine, features a petition of over 31,000 signatories with science degrees who have signed a statement claiming that human release of greenhouse gases is not causing disruption of the Earth's climate (the so-called "Oregon Petition"). The petition is used to argue that there is no scientific consensus on human-caused global warming. However, this argument is misleading as the minimum qualification required to be a signatory is a Bachelor's degree in science. Consequently, the 31,000 signatories comprise only around 0.3% of the 10.6 million U.S. science graduates since the 1970/71 school year (NCES 2009). Further, over 99% of the signatories have no expertise in climate science. The use of non-experts to cast doubt on expert agreement is known as the "fake experts" strategy (Diethelm & McKee, 2009). The misinformation text (406 words) consisted of a mixture of text and a screenshot of the signed Oregon Petition.

The inoculation intervention explained the technique of "fake experts", namely citing a large group of people who convey the impression of expertise while not actually possessing the relevant scientific expertise. Specifically, the text used the example of a tobacco industry ad featuring tens of thousands of perceived (but not actual) experts endorsing a particular brand of cigarette, and compared this approach to opponents of climate action citing long lists of scientists dissenting against climate change. The inoculation text (358 words) consisted of a mixture of text and a figure of a tobacco ad with the text ‘20,679 Physicians say “Luckies are less irritating”’ (Gardner & Brandt, 2006). The inoculation text did not include any information explicitly pertaining to the scientific consensus on AGW—the focus of the text was to neutralize the influence of misinformation by explaining the underlying technique used to mislead. The full intervention texts are available in Sections S1 and S2 of the Supporting Information. Participants exposed to the misinformation intervention were shown debriefing text after completing the survey (provided in Section S3 of the Supporting Information).

Participants’ post-intervention climate attitudes were measured via a survey. The survey included 36 items (listed in Table S1) plus between zero (for the control group with no text interventions) and two attention-filter items—designed to ensure participants were attending to the interventions. All survey items were compulsory and participant data was only delivered by Qualtrics upon full completion of all survey items and correct entry for attention filters.

Six constructs were measured that were relevant to the present article: free-market support, perceived consensus, AGW acceptance, attribution of long-term climate trends to human activity (henceforth “attribution”), trust in climate scientists, and mitigative climate policy support (henceforth “policy support”).[1] Free-market support was used as a proxy for political ideology, using five items developed by Heath and Gifford (2006). Perceived consensus was assessed on a single scale from 0 to 100%. AGW acceptance was measured using five items from Lewandowsky, Gignac, and Vaughan (2013). Attribution was measured using three scales (ranging from 0 to 100%) estimating the human contribution to temperature change, sea level rise, and extreme weather events. Five items measuring trust in climate scientists were adapted

[1] In addition, some items tested people’s views on how others might be affected by the experimental messages. Those were collected for a different project and are not analyzed here.

from Ohanian (1990; used previously in Cook & Lewandowsky, 2016). Policy support was measured with 5 items adapted from Ding et al. (2011).

Results

Separate Type-II ANOVAs for the five dependent variables perceived consensus, AGW acceptance, attribution, trust in climate scientists, and policy support were performed using the Car package for the R statistical programming environment (Fox & Weisberg, 2011), with free-market support as a continuous predictor and the inoculation and misinformation interventions as fully-crossed factors. Table 1 summarizes the means and standard deviations of the dependent variables for each intervention group, while Table 2 summarizes the ANOVA results.

Table 1

Means (Standard Deviations) across Interventions for Experiment 1

Dependent Variable	Control	Misinformation-only	Inoculation-only	Inoculation + Misinformatiion
Perceived consensus	54.5 (25.7)	44.5 (30.6)	50.4 (27.6)	51.6 (28.4)
AGW acceptance	3.39 (.72)	3.29 (.97)	3.36 (.79)	3.48 (.74)
Attribution	44.7 (26.2)	40.6 (29.6)	46.3 (29.0)	40.3 (26.1)
Trust in climate scientists	3.06 (.47)	3.12 (.37)	3.03 (.47)	3.02 (.37)
Policy support	3.60 (.75)	3.44 (.92)	3.55 (.81)	3.67 (.67)

Table 2

ANOVA Results for Experiment 1

Dependent Variable	Effects	η_p^2	F	p
	Inoculation	.021	.065	.799
	Misinformation	.004	2.85	.092
	Free-Market Support	.102	41.864	<.001***
Perceived consensus	Inoculation × Misinformation	.008	3.331	.069
	Inoculation × Free-Market Support	.023	8.217	.004**

	Misinformation × Free-Market Support	.008	2.869	.091
	Inoculation × Misinformation × Free-Market Support	.013	5.198	.023*
AGW acceptance	Inoculation	.019	.371	.543
	Misinformation	.009	.030	.862
	Free-Market Support	.365	218.018	<.001***
	Inoculation × Misinformation	.013	1.098	.295
	Inoculation × Free-Market Support	.022	7.656	.006**
	Misinformation × Free-Market Support	.010	3.549	.060
	Inoculation × Misinformation × Free-Market Support	.017	6.764	.010*
Attribution	Inoculation	.014	.020	.888
	Misinformation	.001	4.440	.036*
	Free-Market Support	.178	82.057	<.001***
	Inoculation × Misinformation	.009	.567	.451
	Inoculation × Free-Market Support	.014	5.112	.024*
	Misinformation × Free-Market Support	.004	1.339	.248
	Inoculation × Misinformation × Free-Market Support	.007	2.957	.086
Trust in climate scientists	Inoculation	.000	2.225	.137
	Misinformation	.005	.426	.514
	Free-Market Support	.004	2.006	.158
	Inoculation × Misinformation	.000	.680	.410
	Inoculation × Free-Market Support	.001	.326	.569
	Misinformation × Free-Market Support	.004	1.666	.198
	Inoculation × Misinformation × Free-Market Support	.001	.309	.579
Policy support	Inoculation	.028	.738	.391
	Misinformation	.005	.203	.653
	Free-Market Support	.310	168.382	<.001***
	Inoculation × Misinformation	.001	2.546	.111
	Inoculation × Free-Market Support	.033	12.829	<.001***
	Misinformation × Free-Market Support	.006	2.227	.136

Inoculation × Misinformation × Free-Market Support	.002	.727	.394

* p < .05. ** p < .01. *** p < .001.

Figure 1 shows the pattern of interactions between the interventions and free-market support on (a) perceived consensus, (b) AGW acceptance, (c) attribution of human activity, and (d) policy support. Due to the lack of change in trust across the intervention groups, trust is not shown in Figure 1. The slopes of the control data (blue dashed lines) show the significant influence of free-market support on all climate beliefs. Exposure to the misinformation (red solid lines) had the effect of lowering perceived consensus from 54.5% in the control group to 44.5% in the misinformation-only group. Misinformation also lowered AGW acceptance (3.39 in control group to 3.29 in misinformation group) and attribution (44.7% in control group to 40.6% in misinformation group) although these differences were not significant. Misinformation also increased polarization, with strong free-market supporters decreasing their climate belief across all four measures. This means that climate misinformation had the greatest influence on political conservatives. The inoculation+misinformation group (green dotted lines) showed less polarization than the control group across all four measures, demonstrating that the polarizing influence of misinformation had been neutralized by the inoculation. The inoculation-only group (purple, dot-dashed lines) also shows less polarization although our primary interest is in groups that were exposed to misinformation.

Fig 1. Predicted response in Experiment 1 from linear regression of observed data. Blue dashed line with triangles represents control group, red solid line with circles represents group receiving misinformation-only intervention, purple dotted line with triangles represents group receiving inoculation-only intervention, green dot-dashed line with squares represents group receiving inoculation before misinformation. Horizontal axis represents free-market support where 1 corresponds to strong disagreement with unregulated markets and 5 corresponds to strong agreement with unregulated markets. (a) Perceived scientific consensus on AGW. (b) Acceptance of AGW. (c) Attribution of human activity to global warming trends. (d) Support for climate policy.

While there was no main effect of inoculation, the two-way interaction between free-market support and the inoculation intervention was significant for perceived consensus, AGW acceptance, attribution, and policy support. There was no significant effect from the interventions or interaction terms on trust in climate scientists. The three-way interaction between free-market support, inoculation, and misinformation was significant for perceived consensus and AGW acceptance, marginally significant for attribution, and non-significant for policy support. This indicates that the influence of the inoculation on perceived consensus and AGW acceptance differed depending on the level of free-market support, having the greatest effect on free-market supporters. In other words, inoculation showed the greatest efficacy amongst those who are most vulnerable to influence from misinformation. However, the inoculation was successful in removing the polarizing influence of misinformation, with the inoculation group showing less polarization than even the control group.

Discussion

Experiment 1 demonstrated that misinformation—in the form of “fake experts” casting doubt on a scientific consensus—has a polarizing effect across political ideology. This form of misinformation may be a contributing factor to the increased polarization on climate change among the U.S. public (McCright & Dunlap, 2011). However, an inoculating message that explains the misinforming technique without mentioning any specific misinformation fully neutralized the polarizing effect of misinformation. This may indicate that when informed of misleading techniques, free-market supporters resist being misled as they see this as a violation of their right to be well-informed.

From a cognitive perspective, it is possible that the inoculation shifts attention from a heuristic surface level to a deeper level of analysis, allowing people to detect patterns of deception (Kahneman, 2003). This would imply that inoculation interventions boost strategic monitoring when encoding potential misinformation (Ecker, Lewandowsky, & Tang, 2010), consistent with the finding that people in a suspicious state are less vulnerable to the influence of misinformation (Lewandowsky et al., 2005). Experiment 1 thus establishes the potential utility of general inoculations that explain common misinforming techniques, and which can be used to inoculate against different misinforming arguments that employ the same technique.

Experiment 2

Method

Experiment 2 tested the effect of inoculation against misinformation that takes the form of ‘false balance’ media coverage regarding climate change: a news article that presented mainstream scientific views alongside contrarian scientists’ views. False-balance media coverage of this type has been shown to confuse the public on various scientific topics (Dixon & Clarke, 2013; Malka, Krosnick, Debell, Pasek, & Schneider, 2009; Stocking & Holstein, 2009). Two types of information were shown prior to the misinformation—consensus information, which has been shown to significantly increase belief in climate change (Lewandowsky, Gignac, & Vaughan, 2013; Cook & Lewandowsky, 2016; van der Linden et al., 2015), and/or an inoculation explaining the misleading effects of false-balance media coverage.

Participants were thus randomly assigned to one of five groups: a control group and four groups who were presented with misinformation. The misinformation text was a mock news article that first featured scientists presenting research supporting the AGW notion, followed by contrarian scientists rejecting AGW and proposing alternative explanations (S7 in Supporting Information). For the four misinformation groups, consensus information and inoculation information were fully crossed so that prior to the misinformation, participants either read consensus information, inoculation information, a message combining both consensus and inoculation information, or no message. The study was approved by the Human Research Ethics Committee at the University of Western Australia, with participants indicating written consent through participation in the online survey.

Participants. Participants (N = 714) were a U.S. representative sample recruited through Qualtrics.com, selected by gender, age, and income demographics in the same fashion as Experiment 1 (49.0% female, average age 48 years, SD = 15 years). Entries with a null perceived consensus (n = 18), null age (n = 2) or age greater than 100 (n = 2) were eliminated. Outliers in the time taken to complete the survey (n = 15) were eliminated according to the outlier labelling rule. Participants were randomly allocated to one of five groups: Control (n = 142), Misinformation (n = 145), Consensus/Misinformation (n = 142), Inoculation/Misinformation (n = 142) and Consensus/Inoculation/Misinformation (n = 143).

Test items. The survey included 37 survey items (Table S2). In addition, the survey included two generic attention filters plus an additional attention filter for groups that included the misinformation intervention to ensure attentive reading of the intervention text. Only participants that filled out all survey items, including correct entry of attention-filter questions, were included in the sample. Seven constructs were measured: AGW acceptance, free-market support, trust in climate scientists, trust in contrarian scientists, attribution of human activity to long-term climate trends, perceived consensus, and policy support. The five items measuring trust in contrarian scientists were adapted from the trust in climate scientists items used in Experiment 1. For example, “Climate scientists can be depended upon to help increase our understanding of what's happening to our climate” was changed to “Scientists who reject the scientific consensus on global warming can be depended upon to increase our understanding of what's happening to our climate” in order to obtain a robust measure of trust in contrarian scientists based on the five measures of trust from Ohanian (1990).

Results

In our analysis, we first ascertained whether there was an effect of the misinformation intervention. Once a significant effect of misinformation was determined, the analysis focused on the two-way interaction between the consensus and inoculation interventions for the four groups that received misinformation. Table 3 summarizes the means and standard deviations of the dependent variables for each intervention group.

Table 3

Means (Standard Deviations) across Interventions for Experiment 2

Dependent Variable	Control	Misinformation-only	Consensus + Misinformation	Inoculation + Misinformation	Consensus + Inoculation + Misinformatiion
Perceived consensus	68.9 (22.5)	63.5 (21.8)	86.1 (18.1)	70.0 (27.9)	83.9 (22.4)
AGW acceptance	3.40 (.86)	3.25 (.94)	3.52 (.87)	3.46 (.90)	3.53 (.93)
Attribution	50.7 (27.0)	47.0 (26.7)	53.4 (28.0)	53.2 (28.4)	54.4 (26.3)
Trust in climate scientists	3.35 (.88)	3.26 (.82)	3.47 (.82)	3.28 (.73)	3.44 (.86)
Trust in contrarian scientists	3.34 (.60)	3.38 (.73)	3.46 (.56)	3.20 (.74)	3.27 (.75)
Policy support	3.60 (.75)	3.44 (.92)	3.55 (.81)	3.55 (.81)	3.67 (.67)

Effect of misinformation. A *t*-test was conducted to compare perceived consensus in the control condition (M = 68.9, SD = 22.5) versus the condition that received misinformation only (M = 63.5, SD = 21.8), finding a significant difference; $t(284) = 2.05$, $p = .04$. This indicates that misinformation in the form of false-balance media articles has a negative effect on public perception of scientific consensus. The effect of misinformation was not as strong on the other dependent variables, and failed to reach statistical significance for the other variables.

Effect of various primings before misinformation. The next stage of our analysis focused on the four groups that received misinformation (i.e., excluding the control group), in order to determine the effect of consensus information and inoculation presented prior to the misinformation. In order to determine which intervention had the strongest effect on perceived consensus, pairwise t-tests between the control group and the four other conditions were conducted. The consensus/misinformation intervention achieved the greatest increase in perceived consensus relative to the control group, $t(269) = 7.083$, $p < .001$. A smaller but still significant effect on perceived consensus was observed for the consensus/inoculation/misinformation intervention, $t(283) = 5.631$, $p < .001$.

For the four groups that received misinformation text (i.e., all groups excluding the control group), separate Type II ANOVAs were performed for the six dependent measures (perceived consensus, AGW acceptance, attribution, trust in climate scientists, trust in contrarian scientists, and policy support) with the consensus and inoculation interventions as fully-crossed factors. Free-market support was included as an additional continuous predictor. Table 4 summarizes the ANOVA results.

Table 4

ANOVA Results for Experiment 2

ANOVA is conducted on 4 groups that received misinformation, forming a 2 × 2 fully crossed design crossing the consensus and inoculation interventions. In the Effects column, Consensus refers to the consensus intervention, Inoculation refers to the inoculation intervention.

Dependent Variable	Effects	η_p^2	F	p
	Consensus	.003	89.831	<.001***
	Inoculation	.001	.723	.395
Perceived consensus	Free-Market Support	.038	27.890	<.001***
	Consensus × Inoculation	.000	4.595	.033*
	Consensus × Free-Market Support	.002	1.191	.276
	Inoculation × Free-Market Support	.001	.371	.543
	Consensus × Inoculation × Free-Market Support	.001	.573	.450
	Consensus	.001	3.398	.066
	Inoculation	.000	.852	.356
AGW acceptance	Free-Market Support	.322	276.911	<.001***
	Consensus × Inoculation	.000	1.189	.276
	Consensus × Free-Market Support	.001	.452	.502
	Inoculation × Free-Market Support	.000	.000	.989
	Consensus × Inoculation × Free-Market Support	.001	.287	.593
	Consensus	.000	1.562	.212
	Inoculation	.000	1.409	.236
Attribution	Free-Market Support	.134	88.288	<.001***
	Consensus × Inoculation	.001	.804	.370
	Consensus × Free-Market Support	.000	.052	.819
	Inoculation × Free-Market Support	.001	.628	.429
	Consensus × Inoculation × Free-Market Support	.001	.613	.434
	Consensus	.014	5.775	.017*
	Inoculation	.000	.421	.516
Trust in climate scientists	Free-Market Support	.181	127.877	<.001***
	Consensus × Inoculation	.000	.021	.885
	Consensus × Free-Market Support	.009	5.226	.023*
	Inoculation × Free-Market Support	.000	.008	.927

	Consensus × Inoculation × Free-Market Support	.000	.251	.617
Trust in contrarian scientists	Consensus	.007	3.122	.078
	Inoculation	.015	8.286	.004**
	Free-Market Support	.130	107.772	<.001***
	Consensus × Inoculation	.003	.143	.705
	Consensus × Free-Market Support	.004	4.187	.041*
	Inoculation × Free-Market Support	.009	3.622	.058
	Consensus × Inoculation × Free-Market Support	.003	2.761	.097
Policy support	Consensus	.009	1.976	.160
	Inoculation	.010	1.444	.230
	Free-Market Support	.149	202.339	<.001***
	Consensus × Inoculation	.005	.372	.542
	Consensus × Free-Market Support	.008	.331	.565
	Inoculation × Free-Market Support	.007	.080	.777
	Consensus × Inoculation × Free-Market Support	.005	2.857	.092

* $p < .05$. ** $p < .01$. *** $p < .001$.

Figure 2 shows the effect of the different interventions on the six dependent variables. The greatest effects were seen in perceived consensus, shown in Figure 2(a). Compared to the Control group (blue solid line, *M* = 68.9%), the misinformation (red dotted line) decreased perceived consensus (*M* = 63.5%), with the greatest effect on strong free-market supporters. Conversely, presenting consensus information prior to the misinformation nullified the negative influence of the false-balance misinformation by increasing perceived consensus (*M* = 86.1%). The reduced slope of the consensus group (purple dot-dashed line) indicates that the consensus information partially neutralized the influence of free-market support. Inoculation (green dashed line) also neutralized the misinformation, with no overall change in perceived consensus (relative to control) amongst participants exposed to both an inoculation and the misinformation.

Presenting the consensus information along with the inoculation text also caused a significant increase in perceived consensus (*M* = 83.9%), although not as great as consensus-only.

Fig 2. Predicted response in Experiment 2 from linear regression of observed data. Blue solid line with triangles represents control group, red dotted line with circles represents group receiving misinformation only, green dashed line with squares represents group receiving inoculation before misinformation, purple dot-dashed line with crosses represents group receiving consensus information before misinformation, orange dotted line with diamonds represent group receiving consensus plus inoculation information before misinformation. Horizontal axis represents free-market support where 5 corresponds to strong agreement with unregulated markets. (a) Perceived scientific consensus on AGW. (b) AGW acceptance. (c) Attribution of human activity to climate trends. (d) Policy support. (e) Trust in climate scientists. (f) Trust in contrarian scientists.

Figures 2(b) through (f) show the effects of the interventions on other dependent variables. The effect of showing consensus information prior to the misinformation was non-significant on AGW acceptance, attribution, and policy support. Trust in climate scientists, shown in 2(e), was significantly increased by the consensus intervention (*M* = 3.25 for misinformation-only and *M* = 3.52 for consensus + misinformation), and there was a significant interaction between the consensus intervention and free-market support, indicating that the consensus information had greatest effect amongst strong free-market supporters. Figure 2(f) demonstrates the effect of the inoculating text on trust in contrarian scientists, with the inoculation group (green solid line) showing decreased trust relative to the control group (blue dashed line). There was a significant main effect of the inoculation on trust in contrarian scientists, causing a decrease in trust (*M* = 3.38 for misinformation-only and *M* = 3.20 for inoculation + misinformation). There was also an interaction between the consensus information and free-market support, with trust in contrarian scientists decreasing mostly for participants with high free-market support.

Amongst the various climate beliefs measured, the effect of false-balance media coverage had the greatest effect on perceived consensus. Accordingly, we also found that an inoculation message was effective in neutralizing the effect of misinformation on perceived consensus, while a consensus message presented with the misinformation was effective in increasing perceived consensus.

Discussion

Experiment 2 found that misinformation in the form of "false balance" media articles significantly decreased perceived consensus, with the effect greatest among political conservatives. This result is consistent with McCright, Charters, Dentzman, and Dietz (2016) who found that false-balance media articles significantly decreased belief about climate change, beliefs about climate science, awareness of climate change consequences, and support for greenhouse gas emission reductions. Also consistent with our results, McCright et al. found that climate misinformation was most effective with conservatives, while having no effect on liberals.

Exploring the efficacy of inoculation interventions on perceived consensus, Experiment 2 found that pre-emptively explaining the potential misleading effect of false-balance media coverage was effective in neutralizing the negative influence of that type of media coverage. This result is consistent with the results of Experiment 1, providing further evidence of the efficacy of inoculation interventions.

While inoculations have been found in this analysis and other studies to be effective in neutralizing misinformation, an open question is the efficacy of positive information that is countered with misinformation. Van der Linden (2016) found that the positive effect of consensus information was cancelled out by the presence of misinformation. In contrast, our Experiment 2 found that consensus information was the most effective intervention in conferring resistance to false-balance media coverage. One possible explanation for the conflicting results may be the nature of the misinformation. In van der Linden (2016), the misinformation explicitly cast doubt on the consensus using text from the Oregon Petition Project (similar to our Experiment 1). In contrast, the misinformation in our Experiment 2 *implied* a lack of consensus in a less direct manner, by presenting mainstream science and dissenting viewpoints concurrently. While the explicit misinformation in Experiment 1 and implicit misinformation in Experiment 2 were both effective in reducing perceived consensus, it is possible that implicit misinformation is more easily neutralized with positive information while explicit misinformation requires an inoculation intervention. The implicit nature of the misinformation in Experiment 2 may also explain the mixed impact on the various dependent variables, with the greatest effect on perceived consensus but weaker effects on the other dependent variables.

Also of note was that the group exposed to consensus information showed less variation across free-market support, indicating a neutralizing influence of consensus information consistent with other studies (Lewandowsky, Gignac & Vaughan, 2013; van der Linden, Leiserowitz, Feinberg & Maibach, 2015). However, this result conflicts with the results of Cook and Lewandowsky (2016), who found that consensus messaging had a polarizing effect on climate beliefs. This is striking given Experiment 2 presented consensus information along with misinformation, whereas Cook and Lewandowsky (2016) presented consensus-only information.

Another confounding study is Deryugina and Shurchkov (2016), which found consensus information had equal impact among liberals, moderates and conservatives. It is difficult, therefore, to draw firm conclusions from the available research. It seems that in general, consensus information has a neutralizing effect, but further research should try to pinpoint boundary conditions under which consensus information may polarize (as found in Cook & Lewandowsky, 2016).

Conclusions

Although Experiments 1 and 2 employed different styles of misinformation, both found that inoculation neutralized the influence of misinformation. Our results are consistent with the findings of van der Linden et al. (2016), who observed that combining accurate information with an inoculation explaining the technique underlying the misinformation was effective in neutralizing the misinformation and increasing perceived consensus. The findings from van der Linden (2016) as well as this study further affirm the effectiveness of inoculation in neutralizing the influence of misinformation.

A number of studies point to possible contributors to the efficacy of inoculation. People in a suspicious state are less influenced by misinformation (Lewandowsky et al., 2005). The greater influence of inoculation on political conservatives may be indicative of psychological reactance (a negative reaction to an imposed loss of freedom). To illustrate, after learning that one has been misinformed, one might perceive the misinformation as an attack on one's freedom to be accurately informed, which could lead to psychological reactance and a corresponding resistance to the misinformation.

It is also noteworthy that the inoculations in this study did not mention the specific misinformation that was presented after the inoculation, but rather warned about misinformation in a broader sense while explaining the general technique being used to create doubt about an issue in the public's mind. The purpose of this type of intervention is to stimulate critical thinking through the explanation of argumentative techniques, thus encouraging people to move beyond shallow heuristic-driven processing of information and engage in deeper, more strategic encoding. A consequence of this approach is that generally-framed inoculations could potentially neutralize a number of misleading arguments that employ the same technique or fallacy.

Experiment 2 also found that consensus information was effective in greatly increasing perceived consensus, even in the face of misinformation in the form of false-balance media coverage. The consensus information also partially neutralized the biasing influence of political ideology, consistent with other studies (Lewandowsky, Gignac & Vaughan, 2013; van der Linden et al., 2015). However, further research is necessary given that this result contrasts with the polarizing influence of consensus information observed with U.S. participants in Cook and Lewandowsky (2016).

The efficacy of consensus information is consistent with other research that has found that perceived scientific consensus is a gateway belief, predicting a variety of climate attitudes including policy support (van der Linden et al., 2015). This dynamic has been recognized by opponents of climate action since the 1990s, who identified manufacturing doubt about the scientific consensus as a key strategy in delaying public support for climate mitigation policies (Walker, 1998; Luntz, 2002). This strategic approach has been documented in an analysis of opinion editorials by conservative columnists from 2007 to 2010, which identified the key climate myths employed (Elsasser, & Dunlap, 2012). This study observed a highly dismissive stance towards climate science, with the most frequently used argument questioning the existence of a scientific consensus on climate change. More recently, an analysis of conservative think-tank literature found that arguments against the science of climate change have been on the increase from 2003 to 2013 (Boussalis & Coan, 2016), indicating that misinformation focusing on climate science continues to be utilized strategically.

The ongoing focus on questioning the consensus, in concert with the gateway belief status of perceived consensus, underscores the importance of communicating the consensus (Cook, & Jacobs, 2014; Maibach, Myers, & Leiserowitz, 2014). However, positive consensus messaging is not sufficient, given recent findings that misinformation can undermine positive information about climate change (McCright, Charters, Dentzman, & Dietz, 2016; van der Linden et al., 2016). As a complement to positive messages, inoculation interventions are an effective way to neutralize the influence of misinformation.

The research into the effectiveness of inoculating messages is consistent with education research which finds that teaching approaches directly addressing misconceptions stimulate greater engagement with scientific concepts which results in more effective and longer-lasting learning (Muller, Bewes, Sharma, & Reimann, 2007; Muller, Sharma, & Reimann, 2008). This teaching approach is known as misconception-based learning (McCuin, Hayhoe, & Hayhoe, 2014), also referred to as agnotology-based learning (Bedford, 2010) or learning from refutational texts (Tippett, 2010). Misconception-based learning has been successfully implemented in classrooms (Cook, Bedford, & Mandia, 2014) and a Massive Open Online Course (Cook et al., 2015). Further research into inoculation is recommended in order to inform design of more effective misconception-based learning interventions.

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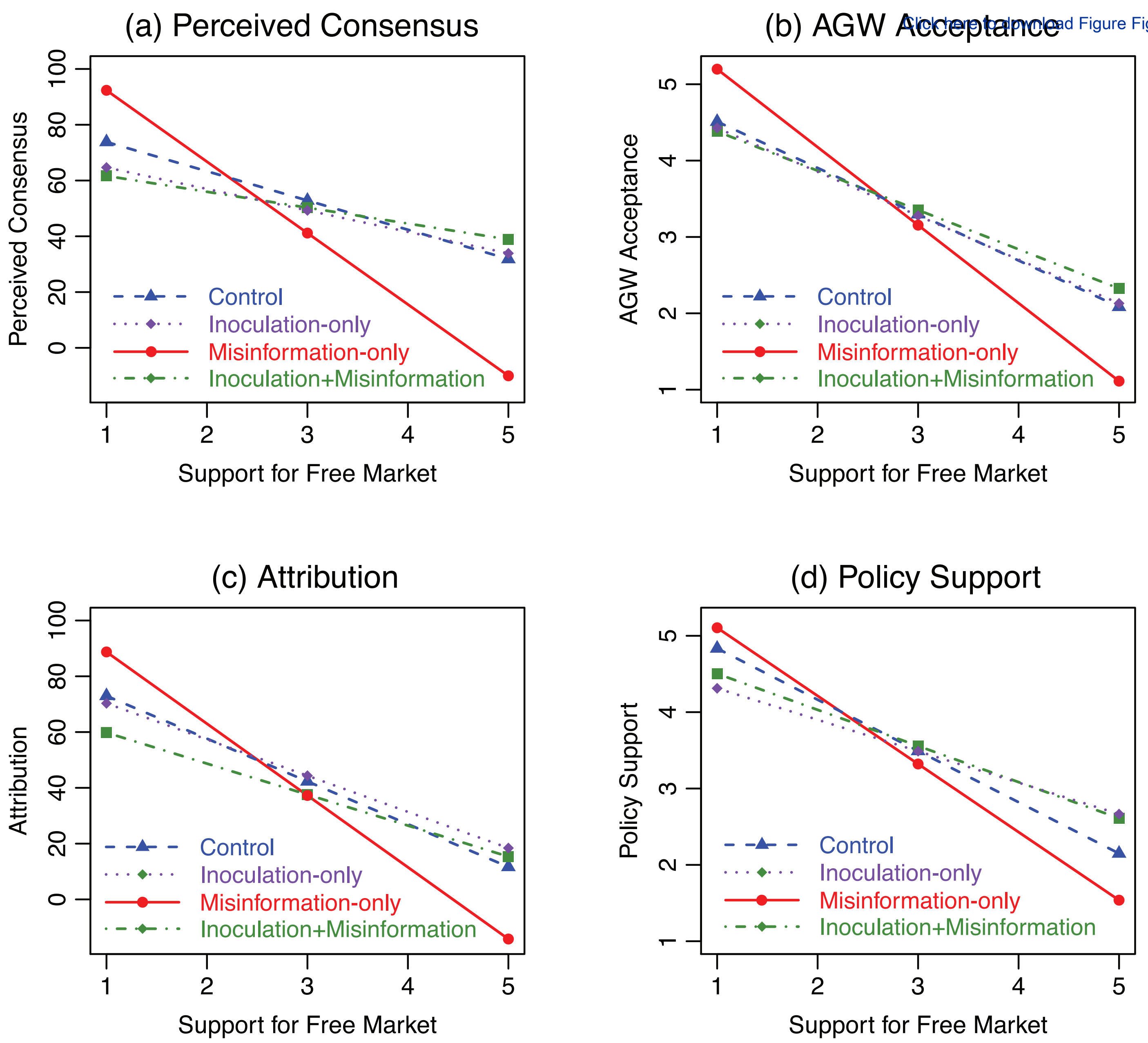
Figure 1


(a) Perceived Consensus
Perceived Consensus
0
20
40
60
80
100
1
2
3
4
5
Support for Free Market
Control
Inoculation-only
Misinformation-only
Inoculation+Misinformation
(b) AGW Acceptance
AGW Acceptance
1
2
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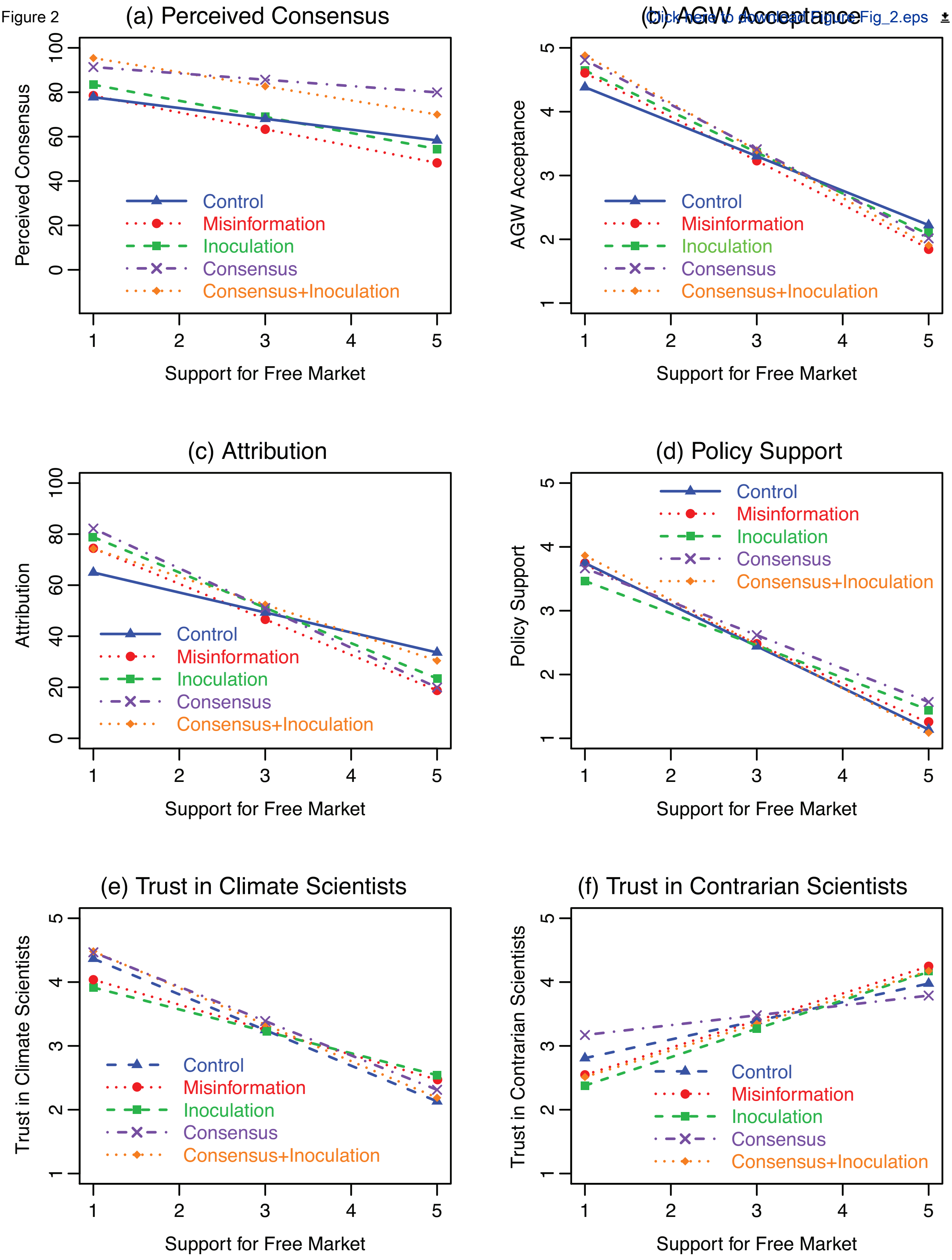
Support for Free Market
Control
Inoculation-only
Misinformation-only
Inoculation+Misinformation
(c) Attribution
Attribution
Support for Free Market
Control
Inoculation-only
Misinformation-only
Inoculation+Misinformation
(d) Policy Support
Policy Support
Support for Free Market
Control
Inoculation-only
Misinformation-only
Inoculation+Misinformation

Figure 2


(a) Perceived Consensus
Perceived Consensus
Support for Free Market
(b) AGW Acceptance
AGW Acceptance
(c) Attribution
Attribution
(d) Policy Support
Policy Support
(e) Trust in Climate Scientists
Trust in Climate Scientists
(f) Trust in Contrarian Scientists
Trust in Contrarian Scientists
Control
Misinformation
Inoculation
Consensus
Consensus+Inoculation

Running head: ALICE IN WONDERLAND REJECTION

The 'Alice in Wonderland' Mechanics of the Rejection of (Climate) Science: Simulating Coherence by Conspiracism

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Abstract

Science strives for coherence. For example, the findings from climate science form a highly coherent body of knowledge that is supported by many independent lines of evidence: Greenhouse gas (GHG) emissions from human economic activities are causing the global climate to warm and unless GHG emissions are drastically reduced in the near future, the risks from climate change will continue to grow and major adverse consequences will become unavoidable. People who oppose this scientific body of knowledge because the implications of cutting GHG emissions—such as regulation or increased taxation—threatens their worldview or livelihood cannot provide an alternative view that is coherent by the standards of conventional scientific thinking. Instead, we suggest that people who reject climate science (or any other body of well-established scientific knowledge) oppose whatever inconvenient finding they are confronting in piece-meal fashion, rather than systematically, and without considering the implications of this rejection to the rest of the relevant scientific theory and findings. Hence, claims that the globe "is cooling" can coexist with claims that the "observed warming is natural" and that the human influence does not matter because "warming is good for us." Coherence between these mutually contradictory opinions can only be achieved at a highly abstract level, namely that "something must be wrong" with the scientific evidence in order to justify a political position against climate mitigation. This high-level coherence accompanied by contradictory subordinate propositions is a known attribute of conspiracist ideation, and conspiracism is therefore almost necessarily implicated when people reject well-established scientific propositions.

The 'Alice in Wonderland' Mechanics of the Rejection of (Climate) Science: Simulating Coherence by Conspiracism

"CO_2 keeps our planet warm . . . ."

— Ian Plimer, Australian climate "skeptic", *Heaven & Earth*, p. 411

"Temperature and CO_2 are not connected."

— Ian Plimer, Australian climate "skeptic", *Heaven & Earth*, p. 278

"Why, sometimes I've believed as many as six impossible things before breakfast."

— The White Queen, in *Through the Looking-Glass, and What Alice Found There*

Over the last 150 years, climate scientists have built an increasingly clear picture of how the greenhouse gas (GHG) emissions that arise from human economic activity are changing the Earth's climate (e.g., IPCC, 2013). Current atmospheric CO_2 levels are higher than at any time since at least 2.6 million years ago (Masson-Delmotte et al., 2013, Figure 5.2), and there is no notable scientific dissent from the consensus position that global warming is happening, is human caused, and presents a global problem (Anderegg, Prall, Harold, & Schneider, 2010; Cook et al., 2013; Doran & Zimmerman, 2009; Oreskes, 2004; Shwed & Bearman, 2010).

Nonetheless, a small but vocal group of contrarian voices exist—mainly outside the scientific community—that deny that greenhouse gases cause climate change or that dismiss the risk of adverse consequences (e.g., Dunlap & McCright, 2011; Lewandowsky, Oberauer, & Gignac, 2013; Lewandowsky, Gignac, & Oberauer, 2013). This dissent almost never finds expression in the peer-reviewed literature (Cook et al., 2013), and when it does, the research typically does not withstand scrutiny (Abraham et al., 2014; Benestad et al., 2015). Instead, the staging ground for climate science denial[1] tends to involve internet blogs and other social media (e.g., Cody, Reagan, Mitchell, Dodds, & Danforth, 2015; Jang & Hart, 2015; Lewandowsky, Oberauer, & Gignac, 2013).

There is strong evidence that the rejection of climate science is primarily driven by ideological factors. Because cutting GHG emissions requires interventions—such as regulation or increased taxation—that interfere with laissez-faire free-market economics, people whose identity and worldview centers around free markets are particularly challenged by the findings from climate science (e.g., Dunlap & McCright, 2008; Dunlap & Jacques, 2013; Lewandowsky, Oberauer, & Gignac, 2013; Lewandowsky, Gignac, & Oberauer, 2013; McCright, Dentzman, Charters, & Dietz, 2013; McCright, Dunlap, & Xiao, 2014).

When a person's worldview and identity, or their livelihood, are threatened by the regulatory implications of climate change, or other environmental risks, they frequently engage in "identity-protective cognition" (Kahan, Braman, Gastil, Slovic, & Mertz, 2007). Identity-protective cognition can manifest itself in a variety of ways. Perhaps the most frequent manifestation is that it moderates people's risk perceptions (Kahan et al., 2007). However, the overwhelming scientific consensus about the causes and risks of climate change—and the impetus for mitigative policies it entails—poses a particular dilemma for people whose identity is threatened by any potential interference with the free market. A mere moderation of risk perception may be insufficient to enable identity-protective cognition in light of the particular challenges posed by the consensus. We suggest that the only cognitive and argumentative options open to identity-protective cognition are either to deny the consensus or to discredit it.

The inconvenient consensus

Some groups have endeavored to deny the consensus by creating a chimerical community of ostensibly dissenting scientists (e.g., the "Oregon Petition"; see Anderson, 2011). Another option is to accept the consensus (at least tacitly), but to glorify the few contrarian scientists as heros, often by appealing to Galileo (Mann, 2015), who oppose the "corrupt" mainstream scientific "establishment." To illustrate, an Australian organization that is dedicated to the opposition to climate science and any mitigation policies calls itself the "Galileo Movement" (`http://galileomovement.com.au/`).

The second option is to (at least tacitly) accept the existence of the consensus but to seek an alternative explanation for its existence. Specifically, instead of accepting the consensus as the result of researchers independently converging on the same evidence-based view, it can be explained via the ideation of a complex and secretive conspiracy among researchers (Diethelm & McKee, 2009; McKee & Diethelm, 2010). Around 20% of U.S. residents have been found to endorse the idea that climate change "is a hoax perpetrated by corrupt scientists who wish to spend more taxpayer money on climate research" (Lewandowsky, Gignac, & Oberauer, 2013). Likewise, many climate contrarian books are suffused with conspiratorial themes (Lewandowsky, Cook, et al., 2015), and when contrarians were asked to indicate their affective responses to climate change, the most common response was conspiratorial in nature, with people frequently citing terms such as "hoax" (N. Smith & Leiserowitz, 2012). When people's responses to consensus information (i.e., a statement that 97% of climate scientists agree on the fundamentals of greenhouse gas driven climate change) are modeled using Bayesian networks, it has been found that for the small segment of the U.S. public who are extremely strong supporters of free market economics, this information activated distrust in climate scientists and led to an ironic reduction in acceptance of fundamental facts about the climate (Cook & Lewandowsky, 2016). The decrease in trust in response to information about expert agreement is compatible with the assumption that people invoke the notion of a conspiracy to escape the implications of the consensus. Accordingly, there is ongoing fascination on contrarian blogs with the "climategate" event of 2009, which arose when climate scientists' private emails were stolen and released on the internet. Those emails were interpreted as constituting evidence of scientific impropriety, and although these allegations were eventually found to be groundless by 9 independent investigations around the world, on contrarian blogs the rhetorical activity devoted to "climategate" more than doubled between 2010 and 2013 (Lewandowsky, 2014). One known element of conspiratorial thinking is its "self-sealing" quality (Bale, 2007; Keeley, 1999; Sunstein & Vermeule, 2009), whereby evidence *against* a conspiratorial belief is reinterpreted as evidence *for* that belief. In the case of climategate, this self-sealing quality becomes apparent not just through the increasing blog fascination with "climategate" despite 9 exonerations—which represent strong evidence against any wrong-doing by scientists—but

also by U.S. Representative Sensenbrenners public branding of exonerations as "whitewash" (http://republicans.globalwarming.sensenbrenner.house.gov/press/PRArticle.aspx?NewsID=

In summary, there is growing evidence for an involvement of conspiracist ideation in the rejection of climate science, both in public discourse and on internet blogs. This finding is unsurprising in light of long-standing knowledge that conspiracist ideation is also involved in the rejection of other well-established scientific propositions, such as the link between the HIV virus and AIDS (Bogart & Thorburn, 2005; Kalichman, 2009) and denial of the benefits of vaccinations (Briones, Nan, Madden, & Waks, 2012; Kata, 2010; Zimmerman et al., 2005). However, research to date has mainly focused on the prevalence of such beliefs and their association with attitudes towards science (Lewandowsky, Oberauer, & Gignac, 2013; Lewandowsky, Gignac, & Oberauer, 2013), or on examining the content of blog discourse and establishing its conspiracist attributes in blind tests (Lewandowsky, Cook, et al., 2015). In this article, we broaden the enquiry of conspiracist ideation to an analysis of the (pseudo-) scientific arguments that are advanced against the scientific consensus on climate change, and how they contrast with the positions of the scientific mainstream.

Scientific coherence vs. conspiracist incoherence

A broad stream of opinion among philosophers of science holds that *coherence* of explanations or theories is a necessary or at least “conducive” criterion for truth (e.g., Douglas, 2013; Laudan, 1984; Roche, 2014; Thagard, 2012). Coherence here refers to the criterion that propositions within the theory must not be contradicting each other—for example, the Earth cannot both be round and flat, and global warming cannot simultaneously be a serious human-caused risk and a natural fluctuation of no concern. Although the epistemological status of coherence is contested (e.g., Glass, 2007; Olsson, 2005; Schubert, 2012), and although even coherent theories can turn out to be wrong (Oreskes, 1999), arguably there is little room for incoherent theories in science.

For the case of climate change, Thagard and Findlay (2011) showed how the mainstream scientific position, namely that GHG emissions from human economic activities are causing the Earth to warm, is coherent and accounts for the available evidence. Their computer simulation of belief revision came to accept the scientific evidence because it maximized coherence among the various pieces of evidence and explanatory propositions.

Conversely, a known attribute of conspiracist thought is that it can appear incoherent by conventional evidentiary criteria. To illustrate, when people reject an official account of an event, they may simultaneously believe in mutually contradictory theories—e.g., that Princess Diana was murdered but also faked her own death (Wood, Douglas, & Sutton, 2012). The incoherence does not matter to the person rejecting the official account because it is resolved at a higher level of abstraction, namely the unshakable belief that the official account of an event is wrong. Thus, “. . . the specifics of a conspiracy theory do not matter as much as the fact that it is a conspiracy theory at all" (Wood et al., 2012, p. 5). For the case of climate change, Thagard and Findlay (2011) showed that the contrarian position, exemplified by the opinion that global warming is a natural fluctuation, is incoherent in comparison to the mainstream scientific position. Thagard and Findlay were nonetheless able to model why people might accept the incoherent contrarian position by adding emotional components (such as "avoid government intervention") to the simulation of belief acquisition. However, the possibility that climate-contrarian discourse is inherently incoherent has not been systematically examined. In the remainder of this article, we provide a preliminary analysis along those lines by analyzing 7 incoherent positions in detail, before summarizing others briefly.

Alice-in-Wonderland states of denial

Although (in-)coherence is a nuanced concept that is not readily measured (Glass, 2007), for present purposes we define incoherence as the simultaneous acceptance or simultaneous proffering of two or more explanatory propositions that cannot be all true at the same time. For example, the proposition that Princess Diana was murdered cannot also be true if the proposition that she has faked her own death is true. Similarly, the quotations of Australian climate "skeptic" Ian Plimer at the outset of this article (Plimer, 2009) are incoherent. It cannot simultaneously be true that "CO_2 keeps our planet warm ..." *and* that "Temperature and CO_2 are not connected." We next show that this incoherence suffuses the public posture of climate science denial, suggesting that it cannot lay a strong claim to scientific or intellectual credibility. We begin by considering the public discourse of denial in the aggregate, where incoherence is introduced by multiple actors, before returning to the level of incoherent statements by single individuals.

Climate sensitivity is low but it is high. One of the most important, but uncertain, variables that determines the extent of future warming is climate sensitivity, defined as the warming that is ultimately expected in response to a doubling of atmospheric CO_2 concentrations from preindustrial times (e.g., Lewandowsky, Risbey, Smithson, Newell, & Hunter, 2014). If sensitivity is high, then continued emissions will increase global temperatures more than when it is low. Low estimates of sensitivity (e.g., $\approx 1.5°$C; Lewis & Curry, 2014) are therefore favored by contrarians, with higher values within the range of consensual IPCC estimates—between $1.5°C$ and $4.5°C$ (Freeman, Wagner, & Zeckhauser, 2015)—being ignored or labeled "alarmist."

Another popular contrarian argument is that the "climate has changed before", which frequently carries the tacit or explicit rhetorical implication that present-day climate change is similarly due to the natural factors that drove past climate changes. This implication is a logical fallacy because the same effect can have multiple causes: Past climate changes were largely driven by slight variations in solar intensity arising from orbital variations or solar cycles, and those events are entirely independent of contemporary GHG-driven global warming. Moreover, the appeal to past periods of warming also entails a commitment to high climate sensitivity: if climate sensitivity were as low as contrarians like to claim ($\approx 1.5°$C), then the minute past variation in intensity of insolation could not have caused the observed warming episodes (PALAEOSENS, 2012).

Either the climate changed in the past because it is highly sensitive to external forces, in which case we are facing considerable future warming indeed, or its sensitivity to the forces triggered by increasing CO_2 concentrations is low, in which case the climate should not have changed in the past. Except that it did.

CO_2 cannot be measured but lags behind temperature. Past levels of atmospheric CO_2 are known with considerable precision from analysis of Antarctic ice cores dating back 400,000 years. One contrarian argument holds that those measurements are unreliable and do not tell us about past CO_2 levels (Jaworowski, 1997).

A notable aspect of past climate changes is that atmospheric CO_2 increased *after* an initial increase in temperatures primarily in Antarctica. This occurs because the initial solar-driven warming that is focused on extreme latitudes is sufficient to trigger the release of CO_2 from the oceans into the atmosphere (because solubility of CO_2 in water decreases with increasing temperature), which in turn amplifies warming and hence leads to more release of CO_2 from the oceans, and so on. Overall, more than 90% of the warming observed during the glacial-interglacial *followed* the increase in CO_2 whereas less than 10% preceded the release of CO_2 and was due to the initial solar pulse (Shakun et al., 2012).[2] By focusing on the lag between temperature and CO_2 in Antarctica and by ignoring the fact that warming occurs *after* the CO_2 increase across most of the globe, contrarians have argued that CO_2 was not the cause of warming in the past but a consequence. By extension, CO_2 also cannot be the cause of warming in the present but must be a consequence of warming that is caused by some other means. (Additionally, this argument relies on a false dichotomy because, like chickens and eggs, atmospheric CO_2 can both be the consequence and the cause of warming.)

Either the ice core record is sufficiently accurate to sustain arguments about the role of CO_2 in past climate changes, or it is unreliable and therefore does not permit any argument either way. There are several additional variants of this incoherence: For example, some contrarians have argued that *contemporary* CO_2 levels cannot be measured with any degree of accuracy (Beck, 2008), whereas others have claimed that CO_2 increases because of emissions from underwater volcanoes (Plimer, 2010).

Global temperature cannot be measured accurately but it stopped warming in 1998. A long-standing contrarian argument has been that the global temperature record is inaccurate and that therefore global warming cannot be measured accurately (Watts, 2009). This argument has often appealed to the presence of "urban heat islands"; that is, the trapping of heat in large urban areas which has increased with greater traffic volumes and economic activity. Alternatively, the argument cites the fact that thermometers may be located near airports or air conditioner exhausts, thereby distorting and artificially amplifying the temperature trend. Another variant of the argument cites adjustments to the temperature record (which are necessary to compensate for variables such as the movement or replacement of thermometers over time) as introducing a warming bias. The scientific literature has shown that those arguments have no qualitative impact on the observed warming trend (e.g., Fall et al., 2011; T. M. Smith, Peterson, Lawrimore, & Reynolds, 2005).

Another long-standing contrarian claim has been that global warming "stopped" in 1998 (e.g., Carter, 2006). Although this claim is based on a questionable interpretation of statistical data (Lewandowsky, Oreskes, Risbey, Newell, & Smithson, 2015; Lewandowsky, Risbey, & Oreskes, 2015b, 2015a), it has been a focal point of media debate for the last decade or more and it has ultimately found entry into the scientific literature under the label of a "pause" or "hiatus" in warming (Boykoff, 2014).

Either the temperature record is sufficiently accurate to examine its evolution, including the possibility that warming may have "paused", or the record is so unreliable that no determination about global temperatures can be made.[3]

There is no scientific consensus but contrarians are dissenting heroes. The pervasive scientific consensus on climate change (Anderegg et al., 2010; Cook et al., 2013; Doran & Zimmerman, 2009; Oreskes, 2004; Shwed & Bearman, 2010; for a synthesis of studies quantifying the consensus on climate change, see Cook et al., 2016) is of considerable psychological and political importance. The public's perception of the consensus has been identified as a "gateway belief" (S. L. van der Linden, Leiserowitz, Feinberg, & Maibach, 2015) that plays an important role in influencing people's acceptance of policy measures. When people are informed about the broad nature of the consensus, this often alters their attitudes towards climate change (Cook & Lewandowsky, 2016; Lewandowsky, Gignac, & Vaughan, 2013; S. L. van der Linden et al., 2015).

Contrarian efforts to undermine the perception of the consensus have therefore been considerable. For example, the top argument leveled against climate change by syndicated conservative columnists in the U.S. between 2007 and 2010 was the claim that there is no scientific consensus (Elsasser & Dunlap, 2013). Other efforts involve the creation of large lists of "scientists" who ostensibly deviate from the consensus, such as the "Oregon Petition", which claims more than 31,000 signatories who express their dissent from the consensus view (Dunlap & McCright, 2010; Anderson, 2011). Only a small number of signatories, however, turn out to be actual scientists with expertise in climate change (Anderson, 2011).

A parallel stream of contrarian discourse highlights the heroism of the lone contrarian scientist who dissents from the "establishment" and fearlessly opposes "political persecution and fraud" (e.g., Solomon, 2008).

Either there is a pervasive scientific consensus in which case contrarians are indeed dissenters, or there is no consensus in which case contrarian opinions should have broad support within the scientific community and no fearless opposition to an establishment is necessary.

The climate cannot be predicted but we are heading into an ice age. The argument that future climate change cannot be predicted with any accuracy is commonly expressed in the form that weather forecasters cannot predict next week's weather so how can they possibly predict climate over the next century (Hickman, 2010). This argument is fallacious because it conflates weather (short-term, localised changes subject to internal variability) with climate (long-term, wide-scale regional or global changes driven largely by external forcing). Predictions of the former are highly sensitive to imprecision in the estimates of initial values (i.e., the current state of weather) and hence lose skill after several days, whereas projections of the latter—they are projections, not predictions; Risbey et al. (2014)—are insensitive to initial values, and are instead aggregated across numerous possible initial states to extract the long-term anthropogenic climate signal from among the natural variability.

Setting aside the fallacious nature of the argument regarding weather forecasts, contrarians have also argued that the future climate is headed towards an ice age, most commonly attributed to decreased solar activity (Johnson, 2013). This prediction has been falsified by climate modelling that found that decreased solar activity will have a miniscule effect compared to the warming effect from greenhouse gas emissions (Feulner & Rahmstorf, 2010). Setting aside falsification of the prediction, the inherent contradiction in this pair of arguments is to argue that future climate cannot be predicted while also predicting a future ice age (Rose, 2010).

Extreme events cannot be attributed to global warming but snowfall disproves global warming. While a growing body of research has attributed a statistical increase in extreme weather events to global warming (Coumou, Petoukhov, Rahmstorf, Petri, & Schellnhuber, 2014; Min, Zhang, Zwiers, & Hegerl, 2011; Pall et al., 2011), attributing a single extreme weather event, such as a *particular* drought or flood, to observed changes in climate is still a difficult exercise. Nonetheless, recent research has increasingly attempted to attribute specific events to global warming (Hansen, Sato, & Ruedy, 2012; Otto, Massey, van Oldenborgh, Jones, & Allen, 2012; Rahmstorf & Coumou, 2011). In some cases, attribution can be made with considerable confidence, for example involving the ongoing Mediterranean drought (Hoerling et al., 2012; Kelley, Mohtadi, Cane, Seager, & Kushnir, 2015).

Those attribution events are largely ignored by contrarians, who instead focus on the—partially accurate—claim that it is problematic to attribute single extreme events as evidence for global warming (Taylor, 2011). In direct contradiction to that claim, they also cite examples of extreme cold as evidence against global warming (Booker, 2008). In one widely reported instance, a U.S. Senator (James Inhofe, R, Oklahoma) displayed a snowball in the U.S. Senate to argue against global warming.

The Greenland ice sheet cannot collapse but Greenland used to be green in Medieval times. If the Greenland ice sheet were to completely melt, it would contribute around 7 metres to global sea level rise (Church et al., 2013). One contrarian argument is that Greenland is not capable of this type of catastrophic collapse (Ollier, 2007), based on the premises that Greenland's glaciers are not melting from the surface down, and that they are not sliding down an inclined plane lubricated by meltwater. Both of those premises are false (Colgan, Sommers, Rajaram, Abdalati, & Frahm, 2015; Phillips, Rajaram, Colgan, Steffen, & Abdalati, 2013), with ice loss from Greenland in recent years greater than at any time since at least 1840 (Box & Colgan, 2013).

At the same time, contrarians also argue that Greenland used to be green in the times of the Vikings (Bolt, 2007), implying that significant amounts of the ice sheet was melted (while incidentally failing to acknowledge the metres of sea level rise that would have accompanied such a degree of melt). This argument follows the same fallacious reasoning as the common myth "past climate change disproves human role in modern global warming." If Greenland was so sensitive to temperature that it had suffered a significant collapse in Medieval times, that would imply a heightened sensitivity to human-induced warming now. If Greenland is sensitive to warming, it cannot be safe from collapse.

Other incoherent arguments. Over one hundred incoherent pairs of arguments can be found in contrarian discourse. (See `www.skepticalscience.com/contradictions.php`). We have explored a representative sample in some detail. For illustration we show several others in Table 1.

Individual cognition vs. group behavior. Our analysis was performed at the aggregate level; that is, we considered the incoherence of collective argumentation among a "community" of like-minded individuals as if it were a single intellectual entity. It is possible, therefore, that individuals within this community would only hold one or the other of two incoherent views, and that each person considered in isolation would not be incoherent.

Our response is fourfold: First, at a purely methodological level, our analysis fits within established precedent involving the scholarly examination of communications from heterogeneous entities such as the U.S. Government (Kuypers, Young, & Launer, 1994) or the Soviet Union (Kuypers, Young, & Launer, 2001) as if it were a single intellectual entity. Second, in psychological research, numerous psychological constructs—such as cognitive dissonance or authoritarianism—have been extended to apply not only to individuals but also to groups or indeed entire societies (e.g., Moghaddam, 2013). Third, as our introductory quotations of Ian Plimer demonstrated, incoherence is demonstrably also present within the arguments offered by the same individual. In further support, Table 2 lists a number of contradictory statements that, unlike those in the earlier Table 1, were made by the same person on separate occasions.

Finally, even if the observed incoherence were entirely confined to being between the opinions of different individuals, and if climate denial sought to emulate scientific reasoning, then one would expect to detect an on-going process of mutual critique and error checking akin to the self-correction of science (Alberts et al., 2015; Longino, 1990, 2002). After all, science strives for—and ultimately attains—coherence through a constant correction process that occurs through peer-review, journal articles, conference communications, graduate training, mentoring, and so on. No such corrective processes can be observed in denialist discourse.

In the eye of the beholder? The absence of any corrective resolution process among climate contrarians raises the question to what extent incoherence is perceived or recognized as a problem by people who hold contrarian views. This question is difficult to answer with any degree of certainty, although one can attempt to make an inference by examining the "revealed preferences" (cf. Beshears, Choi, Laibson, & Madrian, 2008) of contrarians. In the context of climate change, one way in which preferences might be revealed is by the willingness to incur financial risks to back one's position in a bet. Bets have a long history as a tool to reveal people's preferences.

Risbey, Lewandowsky, Hunter, and Monselesan (2015) analyzed the actual historical and likely future odds of a number of different betting strategies on global temperatures from the late 19th century to 2100. Risbey et al. found that all possible 15-year bets since 1970 were won by bettors positing continued warming, and that bets against greenhouse warming are largely hopeless now.

It is notable that although contrarians readily claim that the Earth will be cooling in the future, most are unwilling to bet on their stated position (Annan, 2005). The experiences of Nobel Laureate Brian Schmidt, of the Australian National University, who offered a bet to an Australian "skeptic" (a business adviser of former Prime Minister Tony Abbott) are illuminating in this regard (Cook, 2015). The widespread reluctance to engage in bets by contrarians suggests that their public posture differs from their actual knowledge, and that they *know* that any such bet would be hopeless (Risbey et al., 2015). The unwillingness to bet is thus an indication of the over-arching rationality of denial, notwithstanding its argumentative incoherence.

Rational denial

Unlike mainstream science, which is regularly summarized in the IPCC's Assessment Reports, contrarian positions are more diverse, and are spread across a multitude of sources—from internet blogs, to reports produced by "think tanks" (Jacques, Dunlap, & Freeman, 2008), to popular books (Dunlap & Jacques, 2013). Although this diversity makes it challenging to identify the over-arching level of abstraction at which contrarian positions may achieve the coherence that is lacking in their (pseudo-) scientific arguments, there is little doubt that the common denominator among contrarian positions is the conviction that climate change either does not exist or is not human caused, and that either way it does not present a risk (or if it does, then adaptation will deal with the problem). Any mitigation efforts would thus be misplaced and add an unnecessary burden on the economy. In a nutshell, the opposition to GHG emission cuts is the unifying and coherent position underlying all manifestations of climate science denial.

Accordingly, contrarian activities are supported by the injection of considerable funds by vested and political interests (Brulle, 2013); most climate-"skeptic" books have links to conservative think tanks (Dunlap & Jacques, 2013); and fossil-fuel interests have interfered with scientific assessments (Mooney, 2007). As noted earlier, Thagard and Findlay (2011) has shown that when those political goals are represented as strong emotional components within a rational belief system that is devoted to seek maximal coherence, the system will adopt a "skeptic" position notwithstanding the fact that it is less commensurate with the evidence than the mainstream scientific position. Similarly, Cook and Lewandowsky (2016) have shown within a Bayesian framework that ironic updating of beliefs—that is, becoming *more* entrenched in one's position in light of contrary evidence—can be modeled by a rational belief-updating system under some circumstances. For example, Cook and Lewandowsky (2016) showed that participants who strongly support free-market economics may respond to climate-consensus information by lowering their acceptance of human-caused global warming. This ironic "backfire" effect was entirely rational because people adjusted their trust in climate scientists downward, thereby accommodating information about the consensus without requiring an adjustment of belief in the science—because if scientists cannot be trusted, then they would likely collude to create the appearance of a consensus.

If the coherent goal of contrarian activities is the prevention of political action, then argumentative incoherence—or other manifestations of conspiracist thought—are irrelevant, from the contrarians' perspective, so long as it does not interfere with achievement of that goal. There is some evidence that conspiratorial content is not detrimental to achieving the objectives of preventing or delaying policy action. On the contrary, it has been shown that the mere exposure to conspiracy theories involving global warming decreases pro-environmental decision making and the intention to reduce one's carbon footprint (Jolley & Douglas, 2013; S. van der Linden, 2015). Similarly, McCright, Charters, Dentzman, and Dietz (2016) and Ranney and Clark (2016) have shown that exposure to misleading statistics about climate change can adversely impact people's attitudes. Thus, from a purely pragmatic perspective, research to date has failed to identify a discernible cost—in terms of political effectiveness—of the conspiracist aspect of contrarian discourse. As a political strategy, organized denial of climate science appears to "work"—a judgment supported by the fact that written material arguing against mainstream science conveys greater certainty, and hence may have greater persuasive impact, than scientifically-founded material (Medimorec & Pennycook, 2015).

Conclusion

There is considerable evidence that the rejection of (climate) science involves a component of conspiracist discourse. In this article, we provided preliminary evidence that the pseudo-scientific arguments that underpin climate science denial are mutually incoherent, which is a known attribute of conspiracist ideation. The lack of mechanisms to self-correct the scientific incoherencies manifest in denialist discourse further evidences that this is not the level at which rational activity is focused, and we must move to a higher level, looking at the role of conspiracist ideation in the political realm. At that political level, climate denial achieves coherence in its uniform and unifying opposition to GHG emission cuts. The coherent political stance of denial may not be undercut by its scientific incoherence. Climate denial is therefore perhaps best understood as a rational activity that replaces a coherent body of science with an incoherent and conspiracist body of pseudo-science for political reasons and with considerable political coherence and effectiveness.

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Footnotes

[1] In current scholarly usage the term "denial" is often reserved to describe an active public denial of scientific facts by various means, such as the use of rhetoric to create the appearance of a scientific debate where there is none (Diethelm & McKee, 2009; McKee & Diethelm, 2010). We use denial as a noun that describes a political or discursive activity but we avoid labels such as "denier" or "denialist" that categorize people. There are people who deny scientific facts, but they are not "deniers"—they are people who chose to engage in a particular behavior.

[2] The full picture is more nuanced and includes several other feedbacks and processes than can be presented here.

[3] A possible escape from incoherence is to soften the claim about the data being unreliable to "the data exaggerate warming". Warming might indeed have stopped if the data over-estimate warming.

Table 1

Sample of Additional Incoherent Arguments

Argument 1	Argument 2
TREND and FACT DENIAL	
Future climate cannot be predicted	We are heading into an ice age
Greenhouse effect has been falsifed	Water vapour is the most powerful greenhouse gas
Paleo-temperature proxies are unreliable	The middle ages were warmer.
Other planets are warming	It's cooling
Global temperature does not exist	It cooled mid-century
ATTRIBUTION DENIAL	
Paleo-temperature proxies are unreliable	The middle ages were warmer
Global warming theory is not falsifable	Global warming has been falsifed
Warming causes CO_2 rise	There's no correlation between CO_2 and temperature
Mars is warming	Mars is colder despite all the CO_2
CO_2 was higher in the past	CO_2 measurements are suspect
CO_2 was higher in the 1800s	It warmed before 1940 when CO_2 was low
Temperature proxies are unreliable	CO_2 lags temperature
Global warming is caused by waste heat	Humans are too insignificant to affect global climate
Extreme events cannot be attributed to global warming	Snowfall disproves global warming
IMPACT DENIAL	
It's not bad	There's no such thing as an ideal climate

CO_2 is plant food	CO_2 is just a trace gas
SOLUTION and POLITICAL DENIAL	
My country should not cut emissions	Global warming is natural
China needs to cut emissions	Global warming is unstoppable
Global warming is a socialist plot	The Nazis invented global warming

Table 2

Individuals contradicting themselves

Argument 1	Argument 2
Water vapour tends to follow temperature change rather than cause it. At higher temperatures there is more evaporation and higher water vapour concentrations. At lower temperatures, the opposite occurs. Water vapour is an amplifier rather than a trigger (Plimer, 2009).	Contrary to popular belief, the carbon cycle does not control climate. It is the water cycle that does and water vapour is the main greenhouse gas in the atmosphere (Plimer, 2009).
The global warmth of the Cretaceous has been attributed to elevated levels of CO_2 in the atmosphere (Plimer, 2009).	The proof that CO_2 does not drive climate is shown by previous glaciations (Plimer, 2009).
Replacement of high altitude forests by mixing with low altitude forests to create greater species diversity has happened in previous times of warming and would be expected in another warming event (Plimer, 2009).	Even if the planet warms due to increased atmospheric CO_2, it is clear that plants will not feel the need to migrate to cooler parts of our planet (Plimer, 2009).

[The hot spot] is broader than just the enhanced greenhouse effect because any thermal forcing should elicit a response such as the "expected" hot spot (Christy, 2013).	The models mostly miss warming in the deep atmospherefrom the Earth's surface to 75,000 feet—which is supposed to be one of the real signals of warming caused by carbon dioxide (McNider & Christy, 2014).
As attested by a number of studies, near-surface temperature records are often affected by time-varying biases ... To address such problems, climatologists have developed various methods for detecting discontinuities in time series, characterizing and/or removing various nonclimatic biases that affect temperature records in order to obtain homogeneous data and create reliable long-term time series (Fall et al., 2011).	In the business and trading world, people go to jail for such manipulations of data (Anthony Watts cited in Lott, 2013).

The reality is that the Earth's climate system is far more complex than that: It isn't just a linear relationship between CO_2 and temperature, it is a dynamic ever-changing one, and climate is tremendously complex with hundreds of interactive variables and feedbacks (Anthony Watts cited in Stafford, 2013).	"global warming" suggests a steady linear increase in temperature, but since that isn't happening, proponents have shifted to the more universal term "limate change," which can be liberally applied to just about anything observable in the atmosphere (Anthony Watts cited in Stafford, 2013).

Chapter 6

Raising climate literacy through agnotology-based learning

This chapter is presented in the format of a journal article manuscript.

Cook, J., Bedford, D. & Mandia, S. (2014). Raising climate literacy through addressing misinformation: Case studies in agnotology-based learning. *Journal of Geoscience Education*, *62*(3), 296-306.

Foreword

Agnotology is the study of ignorance, with an emphasis on the cultural production of ignorance using misinformation (Proctor, 2008). As seen in earlier chapters, the presence of misinformation has a negative influence on public levels of climate literacy. However, misinformation also presents an educational opportunity. Explicitly refuting myths and misconceptions has been observed, across several decades of educational research, to be one of the most effective means of teaching (Tippett, 2010). This teaching approach is known as agnotology-based learning (Bedford, 2010) or misconception-based learning (McCuin, Hayhoe, & Hayhoe, 2014).

Agnotology-based learning involves explicit mention and refutation of misconceptions, as well as communication of factual information. This approach has been observed to achieve greater learning gains compared to lessons that only communicate factual information (Kowalski & Taylor, 2009; Muller, Bewes, Sharma, & Reimann, 2008). It also has a number of additional benefits. It increases students' argumentation skills (Kuhn & Crowell, 2011), fosters critical thinking (Berland & Reiser, 2008) and provokes more student interest (Mason et al., 2008).

The term agnotology-based learning was coined by Bedford (2010). Bedford applied this teaching approach in his class on climate change, instructing his students to scrutinize misinformation texts such as the novel *State of Fear* (Crichton, 2004), which rests on the premise that climate change is a hoax, and critique the text's arguments. This approach has students actively engaging with the scientific concepts taught earlier in the course, rather than passively absorbing it.

In 2014, I co-authored a paper with Bedford and Scott Mandia, who teaches climate change at Suffolk County Community College (Cook, Bedford & Mandia, 2014). Both Bedford and Mandia's teaching approaches were examined as practical case studies in agnotology-based learning. The paper included a third case study, using the example of the public communication effort associated with The Consensus Project as described in Chapter 2.

Agnotology-based learning also informed the design of a Massive Open Online Course (MOOC), *Making Sense of Climate Science Denial*, or *Denial101x* (Cook et al., April 2015). MOOCs are an exciting tool offering the opportunity to scale up educational efforts to reach potentially hundreds of thousands of students. The *Denial101x* MOOC explained the fundamental concepts of climate science while simultaneously refuting 50 of the most common myths about climate change. Since April 2015, over 24,000 students from 167 countries have enrolled in *Denial101x*.

I further applied the approach of agnotology-based learning in co-authoring the textbook *Climate Change: Myths and Realities* (Bedford & Cook, in press). The book brings scientific information about climate change to the reader by addressing common misconceptions or myths about climate change, and demonstrating why they are inaccurate or misleading. The purpose of the book is to further promote the adoption of agnotology-based learning in the classroom.

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Raising Climate Literacy Through Addressing Misinformation: Case Studies in Agnotology-Based Learning

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ABSTRACT

Agnotology is the study of how and why ignorance or misconceptions exist. While misconceptions are a challenge for educators, they also present an opportunity to improve climate literacy through agnotology-based learning. This involves the use of refutational lessons that challenge misconceptions while teaching scientific conceptions. We present three case studies in improving climate literacy through agnotology-based learning. Two case studies are classroom-based, applied in a community college and a four-year university. We outline the misinformation examined, how students are required to engage with the material and the results from this learning approach. The third case study is a public outreach targeting a climate misconception about scientific consensus. We outline how cognitive research guided the design of content, and the ways in which the material was disseminated through social media and mainstream media. These real-world examples provide effective ways to reduce misperceptions and improve climate literacy, consistent with twenty years of research demonstrating that refutational texts are among the most effective forms of reducing misperceptions. *© 2014 National Association of Geoscience Teachers*. [DOI: 10.5408/13-071.1]

Key words: agnotology, scientific consensus, climate change, misinformation

INTRODUCTION

Agnotology is the study of ignorance. More specifically, it examines how and why ignorance or misconceptions exist, with a particular emphasis on their cultural production (Proctor, 2008). Misconceptions, also known as alternative beliefs, naïve theories, or alternative conceptions, are beliefs that conflict with currently accepted scientific explanations. Misconceptions occur for all types of students but are particularly evident in students learning from science texts (Tippett, 2010).

For educators seeking to improve climate literacy, of which climate change literacy is an important subset, agnotology involves examining how and why ignorance or misconceptions exist about well-established facts regarding climate change. Ignorance of and misconceptions about numerous aspects of climate change science are especially widespread due in part to an abundance of misinformation about climate change. The process of generating ignorance and misconceptions is known as agnogenesis (Proctor, 2008).

Weber and Stern (2011) argue that several contributing factors are responsible for the discrepancy between scientific opinion and public opinion on the issue of human-caused global warming. These factors are the difficulties in conceptualizing climate change, the difference in scientific understanding between scientists and nonscientists, and competing conceptual frames including those promoting misconceptions. There is now widespread evidence of a persistent agnogenesis campaign intended to sow confusion and doubt about climate science in general and anthropogenic global warming (AGW) in particular (see, for example, Hoggan and Littlemore, 2009; Oreskes, 2010; Oreskes and Conway, 2010). A sharp increase in the number of publications promoting misinformation about climate science in the 1990s coincided with international efforts to reduce carbon emissions (McCright and Dunlap, 2000). This increase in agnogenesis literature coincided with an increase in public skepticism about global warming, suggesting that the campaign to disseminate climate misinformation has been effective (Nisbet and Myers 2007).

The agnogenesis campaign is not only problematic given the societal impacts of climate change, but also for science literacy. Misconceptions are highly resistant to change and interfere with the processing of new knowledge (van den Broek and Kendeou, 2008). However, the presence of climate misinformation also presents an educational opportunity, in that formal or informal instruction can directly refute the inaccuracies in any given piece of misinformation, and lead to a broader perspective on how knowledge is generated.

In less actively contested areas of science, refutational texts have been used to address misconceptions. Refutational texts are text structures that challenge readers' misconceptions, with the purpose of promoting conceptual change. They achieve this by explicitly acknowledging misconceptions about a topic, directly refuting them, and providing an alternative scientific conception. Conceptual change occurs when learners update previously held conceptions or replace them with new conceptions.

Research into cognitive psychology and refutation-style education shows that explicitly addressing misinformation provides an opportunity for achieving conceptual change. Refutational texts have been found to be one of the most

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effective text-based means for modifying readers' misconceptions (Tippett, 2010).

As an approach to climate and climate change science education, agnotology-based learning draws on these findings to propose that climate change misinformation itself be used directly as an educational text. Climate change misinformation can be used in a variety of ways, such as a conventional lecture approach, where individual inaccuracies or misleading statements in a given piece of misinformation are highlighted and refuted by the lecturer, or as a critical-thinking exercise and a test of content knowledge for students or other individuals—can they identify the errors themselves? The research findings mentioned above, and examined in greater detail in the following section, indicate that direct refutation of misinformation can be an effective way to drive conceptual change. However, agnotology-based learning, while related to other approaches intended to bring about conceptual change, is a distinct subset. We suggest that agnotology-based learning can bring about conceptual change not only in content knowledge, but also in epistemology—that is, how people conceive of knowledge more generally. Work in science education that examines conceptual change suggests that this is a particularly powerful combination, but difficult to achieve (Posner et al., 1982). In the following sections, we elaborate on these ideas, and describe several case studies in agnotology-based learning that explicitly address climate misconceptions and study climate misinformation in order to improve climate literacy.

COGNITIVE RESEARCH INTO MISINFORMATION

Misconceptions and misinformation are extremely difficult to remove. When people are presented with refutations of misinformation, they often continue to be influenced by the misinformation even when acknowledging the correction. This is known as the continued influence effect (Johnson and Seifert, 1994). An explanation of the persistence of misinformation is that people build mental models with the myth integrated into the model. When the myth is invalidated, people are left with a gap in their mental model. If nothing is provided to replace the gap, then people may continue to rely on the myth.

In some cases, refutations can actually reinforce misconceptions, a reaction known as a backfire or boomerang effect. One such example is the familiarity backfire effect (Cook and Lewandowsky, 2011). The more familiar people are with information, the more likely they will consider it to be true. One study found that showing participants a flyer debunking vaccine myths resulted in an increase in people thinking the myths were facts (Skurnik et al., 2005). The backfire effect was strongest among older people.

Another adverse reaction to refutations is the overkill backfire effect, which occurs when refutations are too long or complex. When people were asked to generate three counter-arguments against a belief, their level of belief decreased. However, when asked to generate 12 counter-arguments, their belief was reinforced (Schwarz et al., 2007). This is because people prefer simple explanations over complicated ones (Lombrozo, 2007). When it comes to refutations, less is more.

There are several elements to an effective refutation. The risk of a familiarity backfire effect can be reduced if an explicit warning is provided before the myth is presented (Ecker et al., 2010). This puts the person cognitively on guard so they are less likely to be influenced by the misinformation. Another important feature of an effective retraction is an alternative explanation that fills the gap created by the retraction (Johnson and Seifert, 1994). The alternative explanation should be plausible, explain the causal qualities in the initial report, and explain why the misinformation was initially thought to be correct (Seifert, 2002). The risk of an overkill backfire effect is reduced if the alternative explanation is simpler (or at least not more complicated) than the myth (Chater and Vitanyi, 2003).

A succinct encapsulation of the cognitive research into misinformation comes from Heath and Heath (2007, p. 284) who advise communicators to "fight sticky ideas with stickier ideas." The authors explore the concept of "sticky ideas"—messages that are compelling and memorable. One feature of a sticky message is that it arouses curiosity then satisfies it. This is achieved by opening a gap in people's knowledge, then filling the knowledge gap (Loewenstein, 1994). This sequence of "create a gap, fill the gap" is a natural fit for refutations that require creating a gap in a person's model of an event, then filling the gap with an alternative explanation. The very structure of an effective refutation lends itself to compelling, sticky messages.

AGNOTOLOGY-BASED LEARNING: ADDRESSING MISINFORMATION IN EDUCATION

Correcting misconceptions is a significant aspect to education, as "Comprehending why ideas are wrong matters as much as understanding why other ideas might be right" (Osborne, 2010, p. 328). Indeed, efforts to understand and promote conceptual change are at the heart of much of the last thirty years of science education research, a movement largely inspired by Posner and colleagues' (1982) seminal paper. Misconceptions among students abound in all disciplines. For example, students beginning a psychology degree possess a number of misconceptions such as "humans only use 10% of their brains" or "Mozart's music increases infant intelligence" (Kowalski and Taylor, 2009). Because misconceptions interfere with new learning, reducing their influence is imperative.

However, does explicitly refuting myths run the risk of making students more familiar with the myth and causing a familiarity backfire effect? A growing body of evidence indicates that refutational lessons, also known as agnotology-based learning, are one of the most effective means of reducing misconceptions (Muller et al., 2008; Kowalski and Taylor, 2009; see Tippett, 2010 for a review). Refutational-style lectures explicitly mention misconceptions as well as communicate factual information. In contrast, nonrefutational lessons teach accurate information without explicit reference to the misconception. Refutational text has been shown to effect long-term conceptual change across a wide range of grade levels over a period of weeks to several months (Guzzetti et al., 1993).

There are additional benefits to refutational teaching. It has been shown to increase students' argumentative skills and to raise awareness of the relevance of evidence to argument (Kuhn and Crowell, 2011). It fosters critical thinking, encourages students to assess evidence and to draw valid conclusions (Berland and Reiser, 2008; Kuhn and Crowell, 2011). Refutational texts provoke more interest, being preferred by students to traditional textbooks (Manson et al., 2008). Refutation resolves to some degree the issue that knowledge is often imparted as a set of unequivocal facts with a lack of argument in the classroom (Osborne, 2010).

However, there are conditions where refutational lectures can backfire. When students do not properly engage with the text, they can find evidence for previously held misconceptions within the refutation and thus strengthen their false beliefs (Guzetti et al., 1997). Guzetti and colleagues also found that refutations were ineffective when poorly constructed and lacking in clarity.

Understanding why refutation texts are effective enables educators to design material to maximize the chances of conceptual change. The "conceptual change model" suggests four requirements to achieve knowledge revision (Posner et al., 1982). One must cause dissatisfaction with the existing misconception. A replacement to the misconception must be intelligible (e.g., understandable), plausible (e.g., provide believable examples), and fruitful (e.g., potentially lead to new insights and discoveries). This model is consistent with cognitive research finding that to refute misinformation, one must create a gap in the subject's understanding then fill the gap with an alternative narrative.

Further, research indicates that correct and incorrect conceptions must be activated together (van den Broek and Kendeou, 2008). If readers fail to recognize a discrepancy between their incorrect preconceptions and the correct conception, they are less likely to achieve conceptual change learning. The misconception and correct conception should be in close proximity to increase the likelihood of simultaneous coactivation (Kendeou and van den Broek, 2007).

Agnotology-based learning draws on these multiple strands of empirical and theoretical research. We suggest that direct use of climate change misinformation can provide a valuable opportunity to drive lasting conceptual change, in particular because it addresses both content concepts and epistemological concepts—that is, the way students (or informal learners) conceive of knowledge and its production—both of which have been found to be important in bringing about lasting conceptual change, but the latter of which has presented an especially difficult challenge to incorporate (Posner et al., 1982). By bringing misinformation explicitly into an educational setting, content concepts are addressed through the refutation process; by demonstrating that misinformation exists, challenges are posed to learners' epistemological conceptual ecology. In addition, awareness is raised that the enormous quantity of material dealing with climate change in both traditional and new media is not equally reliable or accurate, and that some of this material is even deliberately designed to mislead. Thus, there are a number of reasons why agnotology-based learning is desirable: it is an effective means of reducing misconceptions, fosters critical thinking, improves argumentative skills, and increases interest in educational material.

THREE CASE STUDIES IN AGNOTOLOGY-BASED LEARNING

This paper outlines three case studies in agnotology-based learning, demonstrating how this approach can be applied in a diversity of settings. Two examples are classroom based, applied in U.S. college classrooms. One is a community college and the other a nonselective four-year university with an additional community college mission and a small number of master's programs. Institutions such as these educate a large proportion of U.S. postsecondary students, with associate's degree-granting institutions alone accounting for an estimated 49% of all U.S. postsecondary student enrollment in 2008 (National Center for Education Statistics, n.d.).

The third example is a public outreach conducted by Skeptical Science, a Web site that adopts an agnotology-based learning approach by explaining climate concepts while refuting common myths. The agnotology-based content at this Web site has already been adopted in several university textbooks and curriculum (Cresser et al., 2012; Pipkin et al., 2014). The Web site content has also been adopted by a number of educators—in a survey of over 1,500 high school and college instructors (spanning 50 U.S. states), Skeptical Science was mentioned as a common resource for teaching about global climate change. In particular, two-year college instructors reported that Skeptical Science was the third most commonly used resource after the government resources from NASA and NOAA (Berbeco, pers. comm., 2013). The public outreach in this third example was designed to reduce the public misperception that climate scientists still disagree on human-caused global warming.

Case Study 1: Agnotology and Climate Change Literacy at a Four-Year University in the Western U.S.

The first case study was conducted at a nonselective, four-year university located in Utah in the western U.S. It also offers a small number of master's degree programs, and is charged by the state with providing community college services to the region. Many of the students are among the first in their families to attend college. The student body is almost entirely local, and reflects the region's socially and politically conservative culture. As several studies have recently documented, skepticism about the basic tenets of human-induced climate change are well correlated with such conservatism (e.g., Dunlap and McCright, 2008; McCright and Dunlap, 2011; Hamilton, 2011, 2012), although not necessarily as well correlated with simple political party affiliation (Leiserowitz, 2006; Kahan, Peters et al., 2012). This situation presents a complex and delicate challenge to educators tackling the potentially polarizing subject of climate change.

Agnotology-based teaching in this setting has been previously described by one of the coauthors of this paper (Bedford, 2010). Students in an upper-division, small-enrollment weather and climate class are required to read and assess the veracity of the late Michael Crichton's (2004) engaging but misleading climate change themed thriller, *State of Fear*. This active learning approach aims to address conceptual change in both content and epistemology. As noted earlier, we believe this is a distinctive attribute of agnotology-based learning.

More recently, agnotology-based learning has been extended to a new introductory-level class on global warming, GEOG PS 1400 The Science of Global Warming: Myths, Realities and Solutions, that students may use to meet university general education requirements for physical science. The class has been taught twice as of this writing, with enrollments of around 30 students each time. Agnotology in this class has been applied principally to address the issue of fake experts, or at least experts speaking beyond their areas of expertise. This is one of five common characteristics of science denial movements (Diethelm and McKee, 2009), including efforts to deny the reality, seriousness, and/or human origins of recent climate change: with an overwhelming consensus on climate change within the scientific community (e.g., Oreskes, 2004, 2007; Anderegg et al., 2010; Cook et al., 2013), many of those seeking to discredit the science or minimize the importance of its findings are inevitably not climate scientists themselves. The agnotology-based learning assignment comes late in the semester, after lectures, in-class activities, and homework assignments have established a base level of knowledge about the climate system in general, and climate change in particular.

Particular care is taken in this assignment to avoid alienating students with conservative social and political outlooks—that is, many of the students at the university—by providing an initial case study of fake expertise and flawed arguments regarding a Democratic partisan political issue: the alleged improprieties around the 2004 U.S. presidential election that purportedly allowed George W. Bush to defeat the Democratic candidate, John Kerry. These allegations were ultimately picked up by high-level operatives of the Democratic Party, such as Robert F. Kennedy, Jr., and repeated across the popular media (e.g., Kennedy, 2006). However, as described by the careful journalism of Farhad Manjoo (2008), the case for election improprieties largely relies on naïve interpretations of election data by individuals with backgrounds in statistics but little or no background in political science or the nuances of exit polling. Comparison with expert knowledge reveals the weak foundations on which allegations of a "stolen" election are built, and the case collapses.

By beginning the assignment with a reading, and associated questions, addressing the tendency of *Democrats* to engage in motivated reasoning—finding evidence to fit existing strongly held convictions, even where none really exists—the intention is to allow more conservative (and, in Utah, typically Republican) students to accept the general idea that motivated reasoning exists. Because so much research on the public understanding and acceptance of climate change has focused on conservative/Republican rejection of the mainstream scientific position, it would be easy for an initial strong emphasis on this issue to be perceived as an attack on students' core values, which could result in their shutting out any further information (see, for example, Braman et al., 2007). Thus, by demonstrating the tendency for other groups to engage in motivated reasoning and the use of questionable expertise, the goal is to allow students to accept consideration of the same issue as it applies to climate change. This differs from a more orthodox conceptual change approach in that the cultural roots of misinformation are also directly addressed. Indeed, study of the very *concept* of misinformation, as it applies in two very different contexts (election politics and climate change), is central to this assignment. Thus, epistemological conceptual change is addressed alongside content conceptual change.

The initial discussion of motivated reasoning via the 2004 U.S. presidential election is then followed with a reading of, and associated questions about, a piece of climate change misinformation and its debunking. The precise readings have varied on the two occasions the class has been taught: in the first year, students assessed claims in Bjorn Lomborg's entertaining but misleading book *Cool It!* (Lomborg, 2007). In the second year, students examined an opinion column in the *Wall Street Journal* (Allegre et al., 2012) and its point-by-point rebuttal (Nordhaus, 2012).

For the first iteration of this assignment, students compared *Cool It!* (Lomborg, 2007) with a comprehensive Web site documenting flaws in Lomborg's analysis, lomborg-errors.dk. Students were asked to choose one of Lomborg's arguments regarding climate change, and assess it in the light of lomborg-errors.dk's analysis. As there are numerous claims about climate change made in Lomborg (2007), students were presented with many options; however, most chose to examine a claim found in the introduction, that polar bear numbers had increased despite rising Arctic temperatures. Lomborg-errors.dk indicates that early estimates of polar bear numbers were quite imprecise and characterized by a wide range of possible values; Lomborg's argument can therefore only be made by selecting the lowest value of that wide range at the beginning of the record, and higher values in the ranges from later in the record. Lomborg does not discuss error ranges or uncertainty, and instead presents his numbers as definitive. What appears at first glance to be compelling evidence of polar bear insensitivity to a warming climate is no more than a statistical artifact. The assignment also stimulated a classroom discussion regarding the reliability of lomborg-errors.dk, which indicated that students had become concerned with epistemology. Although the discussion was valuable, and the problems in Lomborg (2007) are apparent to an informed reader (and have been well discussed by Ackerman (2008), confirming the overall accuracy of lomborg-errors.dk), use of Lomborg's book was discontinued, partly because of this issue, and partly because of the book's length.

In the second iteration of this assignment, students read Allegre and colleagues' (2012) *Wall Street Journal* opinion column. Most of the authors are well-established scientists, but the majority are not climate scientists. The column includes many classic "skeptic" arguments about anthropogenic global warming (AGW), including that carbon dioxide is plant food, that there has been no warming for the last ten years, and that the scientific consensus on AGW is weakening and only maintained by persecution of those who question it. Students were asked to summarize the arguments in the column, reflect on their own views about AGW, and then read and reflect on a comprehensive rebuttal (Nordhaus, 2012), all in light of their earlier reading and writing on the 2004 U.S. presidential election. Nordhaus (2012) summarizes work in climate science and policy to refute each of the major points raised in Allegre et al. (2012). His writing is especially powerful, however, when he addresses Allegre and colleagues' economic analysis, because they misuse his own work in order to reach a conclusion that a correct interpretation does not justify. This provides an especially clear example of the importance of not taking seemingly authoritative writing at face value, and further encourages students to consider the full provenance of arguments being made regarding AGW.

By requiring students to think about why the misinformation is incorrect, this exercise constitutes an active learning strategy. Active learning has been shown to be a more effective approach than simply lecturing to students (see Prince, 2004, for a review); further, both content and epistemological conceptual change can be stimulated. Although the number of students who have undertaken these exercises is too small for meaningful quantitative assessment of its effectiveness, anecdotal qualitative evidence suggests students find the exercise both educationally useful and satisfying. Some have spoken of a feeling of empowerment, resulting from a heightened ability to detect and respond to false information. Specific anecdotes include the case of one student, who, referring to Lomborg's writing in *Cool It!*, remarked, "He's so convincing," explaining that it would be easy to accept Lomborg's arguments in the absence of information to the contrary. Another student, asking in class how *Cool It!* could have been published, considering the extensive errors documented at lomborg-errors.dk, prompted a valuable discussion of the publication process and served as a reminder that not all published work, even from a reputable publisher, can or should be thought of as error-free. While discussing the second-year assignment, one student remarked that comparing the skeptic opinion column with the refutation was among the most useful, indeed transformative, learning experiences she had undergone, stimulating a recognition that information on climate change should not be accepted uncritically. Although a serious effort to measure the effectiveness of agnotology-based learning is still required, these anecdotes indicate the potential value of the approach.

Case Study 2: Effective Refutation of Climate Change Myths at a Community College

The second case study was conducted at a publicly supported, open enrollment, multicampus community college located in New York that provides educational opportunities to the local population. More than half the students attend full time and about 75% are under age 25. Most students are underprepared for collegiate work upon entrance. Almost 75% of first-time, full-time freshmen arrive with a poor high school GPA (below 80%), low SAT scores (below 400), or lack a New York State Regents diploma. Sixty percent require one or more developmental reading, writing, or mathematics course. Eighty-six percent of full-time students are employed, 61% work off campus more than 20 hours per week, and 18% spend 20 or more hours each week caring for dependents, thereby limiting their ability to engage with their studies to the extent that might be desirable, or might be possible at more elite institutions. The three-year graduation rate for students is 20%, while an additional 18% transfer prior to graduation (Suffolk County Community College, 2010).

MET103 Global Climate Change is a three-credit lecture course that serves as a science elective for this general student population. First-year high school algebra is the only prerequisite. MET103 has been shown to be an effective model for teaching a climate change elective science course at the community college level (Mandia, 2012), and provides students with the scientific background to understand the role of natural and human-forced climate change so that they are better prepared to become involved in the discussion. Students learn how past climates are determined and why humans are causing most of the observed modern day warming. The technical and political solutions to climate change are also addressed. MET103 was first offered as a special topics course (MET295) in Summer 2011, and after successfully running for two semesters, was approved as a permanent course offering in Spring 2012. To date, the course has been offered six times to a total 169 students. Informal surveys distributed on the first day of class reveal that a large majority of students are aware that the planet is warming but very few understand that human activities are largely responsible for this warming.

Student learning outcomes are assessed by a series of lecture exams featuring short answer questions, biweekly homework assignments in which students locate and summarize current climate-related news stories, and by submitting a research paper near semester's end. The research paper features an agnotology-based learning approach. The SkepticalScience.com (n.d.) Web site is used as the primary student resource for the research paper. Students choose a topic from the list of refutations appearing on the Skeptical Science Web page titled *Global Warming & Climate Change Myths*—a collection of climate myths followed by the scientific refutation and sorted by recent popularity. A series of tabs modeled after ski slope difficulty divides the content into Basic (green circle), Intermediate (blue square), and Advanced (black diamond), although not all myths have all three levels of difficulty. MET103 students are required to carefully study all the information appearing in these tabs and to summarize, in their own words, the information learned from researching the topic. A scoring rubric (Figure 1) is made available to students on day one of the course to clearly define the desired learning outcomes (Mandia, 2013).

The rubric has been designed so that higher scores (80% and above) will be achieved when students describe the myth and its relevance to climate change, clearly articulate why the myth persists, and offer an accurate, science-based refutation by connecting the information at the SkepticalScience.com site with MET103 course notes. Effective refutation techniques to correct misperceptions are modeled throughout the semester by the lecturer and students are encouraged to read *The Debunking Handbook* (Cook and Lewandowsky, 2011) to guide them in an effective refutation of their chosen myth. Of the 169 students who completed

	Name:					
CRITERIA	**5 pt. (100%)**	**4 pt. (80%)**	**3 pt. (60%)**	**2 pt. (20%)**	**1 pt. (10%)**	**0 pt. (0%)**
Introduction: *Thesis statement and relevance to climate*	The writer introduces the topic (specific relevance to climate and skeptic claim).	The writer introduces the topic and its specific relevance to climate. No skeptic claim mentioned.	The writer introduces the topic but does not show relevance to climate or skeptic claim.			Reader has no idea what paper is about.
Body: *Structure/Flow*	Consistently demonstrates a logical and coherent, easy to follow plan of organization.	Organization of the topic is mostly clear and logical.	There is a general flow of information and the order is somewhat logical.	There is a weak flow of information and the order is not very logical.	There is no real flow of information and the order is not logical.	
Science Content: *Coverage/Skepticism* **(2X Score 10 pt.)**	Writer covers the content in depth w/o being redundant. Captures every key point. Skeptic would be convinced.	Writer covers the content in depth w/o being redundant. Captures most key points. Skeptic might reconsider.	Writer covers the content in general w/o being redundant. Captures some key points. Skeptic would not reconsider.	Writer does not fully cover the content. Misses most key points.		Writer misses every key point.
Relation to Notes: *Level of connection to course notes* **(2X Score 10 pt.)**	Relation to course notes is explicitly stated. Significant content relating to notes.	Relation to course notes is explicitly stated. Some content relating to notes.	Relation to course notes is not explicitly stated but can be inferred.			No relation to course notes explicitly nor inferred.
Clarity of Writing: *Easy to understand or confusing?* **(2X Score 10 pt.)**	Writing is clear and concise. Written in student's own words. Very few spelling or grammar mistakes.	Writing is mostly clear and concise. Written in student's own words. Very few spelling or grammar mistakes.	Writing is average. Mostly written in student's own words. Some spelling or grammar mistakes.	Writing is below average. Many spelling or grammar mistakes.		**Plagiarism is rampant. If this box is checked, the student will get a ZERO for the research paper!**
Conclusion: *What was learned?*	Writer makes precise conclusions and/or suggestions for further research. Obvious that writer learned from the research.	Writer makes some conclusions and/or suggestions for further research. Obvious that writer learned from the research.	Writer makes weak conclusions and/or suggestions for further research. Not obvious that writer learned from the research.			No obvious conclusions made.
Source Citations	Correct style within content. Works cited has no mistakes.	Mostly correct style within content. Works cited has no mistakes.	Mostly correct style within content. Works cited has a few mistakes.	Incorrect in-text citations. Works cited has no mistakes.	Incorrect in-text citations. Works cited has a few mistakes.	Incorrect in-text citations. Works cited has many mistakes or is missing.
# of Words Minimum 1000	900-999 -10%	800-899 -20%	700-799 -30%	600-699 -40%		< 600 0 score for paper

FIGURE 1: Rubric for research paper evaluation (Mandia, 2013).

the course, 156 submitted research papers. Fifty-eight percent of these students achieved a high score (above 80%), while 37% mastered the content (scoring above 90%).

Three recent examples of MET103 students are provided. Students Necci, Santalucia, and Buonasera effectively refuted climate change myths while also demonstrating a mastery of course content. These three student assignments have been featured online as examples of effective refutations and can be accessed at Cook (2014). All three assignments achieved a score of 100%, which was well above the two class averages of 72% and 77% from the Spring 2013 semester. Necci's assignment refuted the myth that the Sun is the primary factor forcing recent climate change and not greenhouse gases such as carbon dioxide. Santalucia refuted the myth that hurricanes cannot be linked to global warming. Buonasera refuted the myth that scientists were predicting a coming ice age in the 1970s.

All three student research assignments featured the effective refutation technique described by Johnson and Siefert (1994) by offering an alternative explanation to fill the gap left behind by the refutation. All three also provided a relatively simple alternative explanation deemed to be an effective refutation technique by Chater and Vitanyi (2003), Lombrozo (2007), and Schwarz et al. (2007). Necci's assignment also incorporated a third refutation technique by providing an explicit warning before presenting the myth, thus reducing the familiarity backfire effect described by Cook and Lewandowsky (2011) and Ecker et al. (2010).

Necci begins his writing assignment by providing an explicit warning before presenting the myth. The author writes:

> *This argument is deliberately misleading; intended to shift public opinion by instilling doubt over the validity of climate science in the United States. The objective of this action is to create controversy and debate, allowing for any regulations on greenhouse gas emissions to be delayed for as long as possible.*

Necci then describes how climate changes when there is a radiative imbalance between incoming and outgoing energy. The author educates the reader about total solar irradiance (TSI) and the physics of the greenhouse effect to set up a simple visual model of incoming versus outgoing radiation. The author then reveals that TSI has decreased in the past few decades but global air temperatures have been increasing, which means that incoming solar energy is not forcing the warming. Necci explains that the increased greenhouse effect (less outgoing energy) is the only physical explanation for the modern day warming, which supports the visual in versus out energy model established at the outset of the paper.

Santalucia begins his writing assignment by describing how the planet is being warmed due to humans pumping greenhouse gases into the atmosphere. This warming has led to increased ocean temperatures and higher sea levels—two factors that are leading to more powerful and damaging hurricanes. The author challenges the myth of no trend in hurricanes by citing Holland (2007), who concluded "increasing cyclone numbers has lead (sic) to a distinct trend in the number of major hurricanes and one that is clearly associated with greenhouse warming" (p. 2). Santalucia also makes it clear to the reader that even if the number or intensity of hurricanes were not changing, rising sea levels due to global warming will make every hurricane more damaging via increased storm surges. The author reminds readers who may live far from the coast that they will not be spared the financial burden of these events because federal tax dollars are used to clean up and rebuild after these storms.

Buonasera's writing assignment immediately refutes the myth that scientists were predicting a coming ice age in the 1970s by explaining that the origin of the myth comes from two stories in the popular press (*Time* and *Newsweek*) and not from peer-reviewed scientific journals. The author describes the myth as a classic cherry-pick where a tiny subset of the data is used to represent the entirety of the data. The author then reveals the full data set:

> *From 1965 to 1979, there were a total of seven peer-reviewed studies that predicted global cooling. However, in that same timespan, there were 42 studies that predicted global warming. From 1973 to 1979, the number of scientific papers per year that predicted global warming increased from two to eight. Meanwhile, the number of scientific papers per year that predicted global cooling showed little change in that span of time* (Cook, 2010). *An argument could have been made in the late 1960s and early 1970s that there was no scientific consensus on global climate change, as in 1975 the National Academy of Sciences stated they did not have enough of an understanding to form a conclusion. However, that cannot be stated any longer, as the current stance of the National Academy of Sciences is that global warming is real and is happening* (Cook, 2010).

The MET103 research paper assignment utilizes an active learning strategy because it requires students to actively process course content in order to understand why a given climate change myth is either incorrect or misleading. Combined with training in effective climate-change myth debunking, students are equipped with the skills necessary to address such myths after graduation, potentially encouraging lifelong learning.

Case Study 3: Closing the Consensus Gap using Social and Mainstream Media

Arguably, one of the most significant climate misperceptions involves the level of agreement among climate scientists about AGW. A number of studies have sought to measure the scientific consensus, with surveys of the climate science community finding around 97% agreement among publishing climate scientists that humans are causing global warming (Doran and Zimmermann, 2009; Anderegg et al., 2010). An analysis of 928 papers matching the search "global climate change" from 1993 to 2003 found zero papers rejecting AGW (Oreskes, 2004).

Despite numerous studies finding an overwhelming scientific consensus, the public perception is that the scientific community continues to disagree over the fundamental question of AGW (Leiserowitz et al., 2012; Pew, 2012). This misperception has significant societal consequences—when the public thinks scientists disagree on AGW, they are less likely to support policy to mitigate climate change (Ding et al., 2011; McCright et al., 2013). Consensus also has been shown to partially neutralize the biasing effects of worldview in Australia, with conservatives showing a greater increase in climate belief compared to liberals when presented with consensus information (Lewandowsky et al., 2012). The "consensus gap" is therefore a significant roadblock delaying meaningful climate action.

The persistence of the consensus gap is likely the result of an agnogenesis campaign lasting over two decades designed to cast doubt on the consensus. In the late 1980s, the number of popular publications attacking the scientific consensus sharply increased (McCright and Dunlap, 2000). In 1991, fossil fuel company Western Fuels Association conducted a half-million dollar campaign designed to "reposition global warming as theory (not fact)" (Oreskes, 2010, p. 138). In syndicated opinion pieces written by conservative columnists from 2007 to 2010, the most common climate myth was "there is no scientific consensus" (Elsasser and Dunlap, 2012).

The Skeptical Science team of volunteers undertook a crowd-sourced project, involving scientists and volunteer researchers, with the purpose of continuing and extending Oreskes' 2004 analysis of 928 "global climate change" papers published from 1993 to 2003. The literature search was expanded to include papers matching the term "global warming" from 1991 to 2011, increasing the sample to 12,464 abstracts. The study found that among abstracts expressing a position on AGW, over 97% endorsed the consensus. The study also found that scientific consensus had already formed in the early 1990s and strengthened over the 21 year period. This result was consistent with earlier research.

A public outreach was designed to leverage the peer-reviewed published research (Cook et al., 2013) to publicly promote the scientific consensus with the purpose of reducing the public misperception that climate scientists still disagreed about AGW. The press release promoting the publication of the research was designed to coactivate both the conception of scientific consensus and the misperception of disagreeing scientists. Specifically, the scientific conception was the quantitative information that a 97% consensus exists among climate papers expressing a position about AGW. The myth that scientists disagreed that humans were causing global warming was activated by citing research finding that the public held the misperception of a 50:50 debate (Pew, 2012). An explicit warning prior to activating the myth mentioned the "gaping chasm between the actual scientific consensus and the public perception" (p. 1).

Press releases were issued by the universities of several of the paper's coauthors, based in Australia, the UK, and the U.S. The Institute of Physics, publisher of the journal

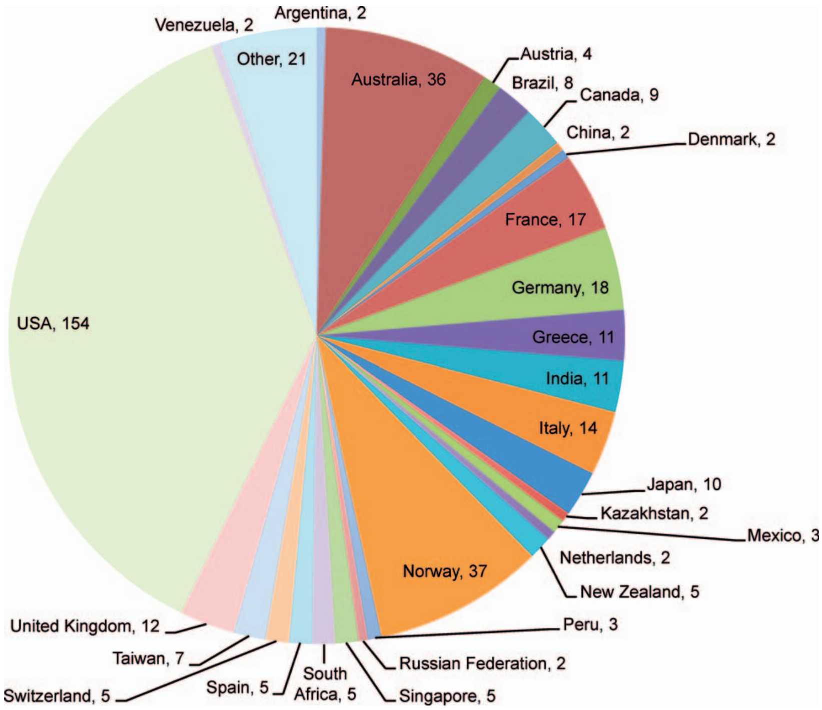

FIGURE 2: Number of media mentions of Cook et al. (2013), divided by country, from 16 May to 3 July 2013. Numbers provided by media-monitoring company Meltwater News, based on keywords selected to monitor online news specific to Cook et al. (2013). Numbers do not include print or broadcast media.

Environmental Research Letters, also issued a press release. Most news reports covered both the key results of the paper and the misperception, ensuring that coactivation of both misconception and scientific conception maximized chances of reducing the misconception. One day after the paper's release, the paper was promoted on President Obama's Twitter account, which features over 31 million followers (Obama, 2013). This resulted in over 2,650 retweets and additional media coverage about the tweet (Hannam, 2013). The paper received global exposure with media coverage divided by country shown in Figure 2.

A major goal of the outreach was to reach beyond the "choir" of blogs and organizations already engaged with the climate issue. Mainstream media attention as well as President Obama's tweet significantly contributed to this goal. Another contributor was coverage in a diversity of media outlets and blogs, on topics as far ranging as finance, health, general science, and farming. The research was even reported in conservative newspapers known for expressing dissenting views on climate change such as *The Australian* (AAP, 2013) and the *Telegraph* (Pearlman, 2013).

To facilitate the goal of reaching the lay public who were not already familiar with climate science, a Web site, theconsensusproject.com, was developed pro bono by New York based design and advertising agency, SJI Associates. The Web site featured shareable images to facilitate viral marketing, which were reposted in numerous blogs and Facebook pages. Several samples are shown in Figure 3, with the second figure demonstrating coactivation of accurate perception and misperception.

Criticisms from blogs that reject the scientific consensus on climate change were anticipated and a pre-emptive FAQ (http://sks.to/tcpfaq) was published simultaneously with the paper publication. This approach is recommended for scientists publishing climate research that is likely to attract criticisms from climate dissenters. The criticisms directed towards Cook et al. (2013) themselves presented a further agnotology-based learning opportunity. As mentioned previously, Diethelm and McKee (2009) identified five characteristics of movements denying a scientific consensus, namely fake experts, logical fallacies, impossible expectations of what research can deliver, cherry picking, and conspiracy theories. These five characteristics of denial were on display in the criticisms of Cook et al. (2013) and a number of examples were examined in an article published in the UK *Guardian* newspaper (Nuccitelli, 2013).

In summary, public misperception about the scientific consensus on climate change was targeted in a communication outreach that sought to reinforce the overwhelming agreement in climate research and to reduce the consensus gap. The outreach received global exposure across a diversity of media outlets. Importantly, mainstream media covered both the key results of the paper and the misperception in a manner consistent with the coactivation structure of refutation texts. While perception of consensus was measured among a representative U.S. sample prior to the

FIGURE 3: Images from theconsensusproject.com designed for viral sharing via social media. Source: SJI Associates, used with permission.

release of Cook et al. (2013), a postpublication measure of perceived consensus has not been conducted to date. Thus, it remains to be seen whether public perception of scientific consensus will have discernibly shifted in response. However, it is anticipated that a shift in awareness among the general public will require a sustained, persistent awareness campaign.

DISCUSSION

Agnotology-based learning has some limitations, particularly in public outreach outside of the classroom. Political ideology has been shown to be one of the strongest predictors of climate attitudes, with conservatives more skeptical of AGW (Heath and Gifford, 2006). It has been shown that higher levels of education tend to increase climate skepticism among Republicans while decreasing skepticism among Democrats (Hamilton, 2011; Kahan, Peters et al., 2012). Similarly, there is a strong correlation between political ideology and perception of consensus. For example, 58% of Democrats think scientists agree on AGW while only 30% of Republicans think scientists agree (Pew, 2012). This indicates political belief has a strong influence on public perception of consensus. Nevertheless, even among Democrats, there is a significant consensus gap, indicating that political bias only partly explains the consensus gap and that general lack of awareness is an ongoing issue.

Two aspects to effectively communicate climate change science are required to close these gaps, especially in the case of public outreach, specifically a two-channel science communication that combines information content (Channel 1) with cultural meanings (Channel 2; Kahan, Jenkins-Smith et al., 2012). The two-channel approach may not be as relevant in an educational setting, although educators are advised to be aware of the biasing influence of ideology when climate science is involved.

In conclusion, 20 years of scholarly research have found that refutational texts are one of the most effective means of reducing misconceptions. We have outlined three case studies that use agnotology-based learning to reduce misconceptions, two in educational settings and one using public outreach. These examples provide anecdotal evidence of the effectiveness of this approach, with students demonstrating strong engagement with the material and reporting transformative learning experiences. Nevertheless, a future area of study would be to quantitatively measure the effectiveness of this learning approach in addressing climate misconceptions.

Despite extensive research indicating the effectiveness of refutation text, textbooks typically contain little or no refutation text. Therefore, publishers and authors are encouraged to adopt refutation text structure in science educational material. Similarly, educators and teachers are encouraged to adopt agnotology-based learning approaches in the classroom. Such approaches are valuable in terms of their educational effectiveness, as demonstrated by research in cognitive psychology and science education, and go some way towards addressing an important recommendation for building a climate and energy literate society: countering climate change denial and manufactured doubt (McCaffrey et al., 2013).

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Chapter 7
Conclusion

Psychological research offers a number of insights and guidelines into the broad issues of effective refutation of misinformation and communication of climate change science. The research described in this thesis, including my own studies, also address more specific questions such as how scientists and science communicators can close the gap between public perception of scientific consensus, and the actual overwhelming agreement among climate scientists.

This seemingly simple question involves a range of psychological processes. How do personal values such as free market support influence attitudes about an issue such as climate change? How do people update their beliefs in response to consensus information, and how do factors such as worldview and trust in scientists interact with the information? What psychological processes are involved when people update their beliefs to correct misconceptions? I have examined these issues through the lens of several different lines of research.

I have co-authored several reviews of the psychological research into misinformation (Cook, Ecker & Lewandowsky, 2015; Lewandowsky et al., 2012). A companion piece to these scholarly reviews is the Debunking Handbook, an accessible, concise summary of the best practices based on the psychological research (Cook & Lewandowsky, 2011).

Misinformation research has found a number of cases where accurate climate information, or retraction of climate misinformation, has been known to result in contrary responses (Feinberg & Willer, 2011; Hart & Nisbet, 2012; Myers et al., 2012). I explored the psychological processes involved in contrary updating by developing a computational cognitive model that used Bayesian Networks to simulate climate beliefs. This research found that an active distrust of climate scientists was a significant factor behind contrary updating in response to consensus information. In certain contexts, a suspicious state can result in positive outcomes, such as suspicion about a government's motives resulting in less vulnerability to misinformation about the Iraq war (Lewandowsky, Stritzke, Oberauer, & Morales, 2005).

Consequently, I explored the possibility of pre-emptively increasing scepticism about the argumentation techniques of misinformation in order to reduce its influence. This led in turn to incorporating the findings of inoculation theory, which neutralises misinformation by exposing people to a "weak form" of the misinformation (McGuire & Papageorgis, 1961). The practical implementation of inoculation theory is consistent with the findings of cognitive psychology – effective refutations consist of an explanation of the facts as well as an explanation of the technique used by the misinformation to distort the facts. I found that generic inoculating messages that explained the misinformation techniques were effective in neutralising the influence of specific misinformation messages (Cook, Lewandowsky, & Ecker, 2016).

In parallel to this basic research, I also explored educational research into agnotology-based learning. This research found that explicitly refuting misinformation is more effective at reducing the influence of misconceptions than simply teaching the facts. This teaching approach is being applied in college classes on climate change (Cook, Bedford & Mandia, 2014) as well as in Massive Open Online Courses (Cook et al., 2015).

All three strands of research – cognitive psychology, inoculation theory and agnotology-based learning – independently converge on a consistent approach to reducing the influence of misinformation. The most important feature of a refutation is placing primary emphasis on facts. However, the myth still needs to be explicitly addressed, in order for the recipient to be inoculated against its influence. Before mentioning the myth, an explicit warning that the myth is about to be mentioned should be provided (Ecker, Lewandowsky, & Tang, 2010). Following the mention of the myth, the technique or fallacy of the misinformation should be explained, allowing the recipient to reconcile the co-existence of the myth with the facts.

While a great deal of research and effort has been expended on climate communication, little attention has been paid to how such communication efforts are undermined by misinformation. Consequently, the scientific community ignored the persistence of climate science denial and the corrosive influence of misinformation at their own peril. Misinformation reduces climate literacy and as a consequence, public support for policies to mitigate climate change (McCright et al., 2016; van der Linden et al., 2016). Scientists and communicators need to adopt an evidence-based approach to climate communication and countering the corrosive influence of misinformation.

This thesis spanned a range of issues all relevant to the issue of climate literacy, scientific consensus and climate misinformation. While spanning a range of disciplines and research questions, it also focused on a narrow question – how do we close the consensus gap? The answer is two-fold: communicate the scientific consensus in a manner consistent with research-based practices, and inoculate the public against the misinforming techniques used to cast doubt on the consensus.

While my research has focused on the specific issue of the scientific consensus on climate change, the principles have broader application to science communication and conceptual change in general. Given the ubiquity of misinformation in many areas, this research consequently has broad relevance.

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Curriculum Vitae

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Education

2012-	Doctorate of Philosophy
	School of Psychology, University of Western Australia, Australia.
1989	B.Sc. First Class Honours, Physics.
	University of Queensland, Australia.

Employment

2011-	Climate Communication Fellow, Global Change Institute, Australia
2010-	Adjunct Lecturer, University of Western Australia, Australia
2007-2011	Webmaster, Skeptical Science, Qld, Australia
2004-2011	Web programmer, PaperWeb Design, Qld, Australia
1996-2009	Web programmer, Illustrator, Sevloid Art, Qld, Australia
1994-96	Graphic Designer, PC Graphic Art, Qld, Australia

Awards

2016 Friend of the Planet award (National Centre for Science Education)

2013 Peter Rawlinson Conservation Award in recognition of an outstanding voluntary contribution to conservation in Australia (Australian Conservation Foundation)

2012 Atlas Award, celebrating heroes of the Climate Movement (Transition Express)

2012 Eureka Prize for Advancement of Climate Change Knowledge (Australian Museum)

Books

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Massive Open Online Courses (MOOCs)

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