Cook, J. (2019). Understanding and countering misinformation about climate change. In Chiluwa, I. & Samoilenko, S. (Eds.), *Handbook of Research on Deception, Fake News, and Misinformation Online* (pp. 281-306). Hershey, PA: IGI-Global.

Understanding and countering misinformation about climate change

John Cook
George Mason University, USA

ABSTRACT

While there is overwhelming scientific agreement on climate change, the public have become polarized over fundamental questions such as human-caused global warming. Communication strategies to reduce polarization rarely address the underlying cause: ideologically-driven misinformation disseminated through outlets such as social and mainstream media. In order to effectively counter online misinformation, we require foundational frameworks that provide comprehensive understanding of the techniques employed in climate misinformation, as well as inform evidence-based approaches to neutralizing misinforming content. This chapter reviews analyses of climate misinformation, outlining a range of denialist arguments and fallacies. Identifying and deconstructing these different types of arguments is necessary to design appropriate interventions that effectively neutralize the misinformation. This chapter also reviews research into how to counter misinformation using communication interventions such as inoculation, educational approaches such as misconception-based learning, and the interdisciplinary combination of technology and psychology known as technocognition.

Keywords: Misinformation, Denial, Skepticism, Inoculation, Climate Change, Global Warming, Misconception-Based Learning, Technocognition

INTRODUCTION

Every six to seven years, the Intergovernmental Panel on Climate Change (IPCC) issue a summary of the state of scientific research into climate change. Over the last few decades, their statements on the human contribution to recent global warming have grown increasingly definitive, from "a discernible human influence on the global climate" in the Second Assessment Report (Houghton et al. 1996) to "human influence has been the dominant cause of the observed warming since the mid-20th century" in the Fifth Assessment report (pp17, Qin et al 2014). Parallel to the strengthening scientific consensus in the IPCC reports, a number of other studies have sought to quantify the level of agreement on human-caused global warming among climate scientists. A synthesis of this research concluded that between 90 to 100% of scientists who publish climate research have concluded that humans are the predominant cause of global warming, with multiple studies converge on 97% consensus (Cook et al., 2016).

Despite strong expert agreement, much of the public remain confused about the reality of human-induced global warming. Only 12% of the American public are aware that the scientific consensus is higher than 90% (Leiserowitz et al., 2017), a misconception referred to as the "consensus gap" to represent the chasm between public perception of consensus and the 97% consensus. The consensus gap is also found among science teachers (Plutzer et al., 2016) and journalists Wilson (2000). The U.S. public are also deeply polarized on the issue of climate change, with political liberals much more accepting of the reality of global warming relative to political conservatives (Cook and Lewandowsky, 2016; Leiserowitz et al. 2017). This polarization has been increasing over time (Dunlap, McCright, & Yarosh, 2016).

Addressing the issue of public polarization over climate change requires acknowledging and addressing the cause. In this case, a major contributor to polarization over climate change is decades of ideologically-driven misinformation campaigns (McCright & Dunlap, 2010). Misinformation about climate change is found in a variety of outlets including mainstream media (Painter and Gavin, 2015) and social media (Harvey et al., 2017). In order to adequately respond to online misinformation about climate change, theoretical frameworks are required to better understand the impact of climate misinformation, the types of arguments employed, and effective interventions. This chapter will explore the research into the psychological impacts of climate misinformation, the techniques employed in denialist arguments, and the efficacy of various interventions in response.

A growing body of research has explored the negative impacts of misinformation. A relatively small amount of climate misinformation, such as a few misleading statistics, is effective in lowering people's acceptance of climate change (Ranney & Clark, 2016). Misinformation targeting the scientific consensus significantly decreases perceived consensus, which subsequently lowers other climate attitudes including policy support (Cook, Lewandowsky, & Ecker, 2017; van der Linden, Leiserowitz, Rosenthal, & Maibach, 2017). Misinformation about climate change also has a polarizing effect, disproportionately influencing political conservatives while having little to no effect on political liberals (Cook, Lewandowsky, & Ecker, 2017; van der Linden, Leiserowitz, Feinberg, & Maibach, 2015). This means that climate misinformation serves to exacerbate what is already a politically polarized public debate.

An arguably more pernicious element of misinformation is its ability to cancel out the positive effects of accurate information. Denialist frames have been shown to reduce the positive effect of a number of different climate frames (McCright, Charters, Dentzman, & Dietz, 2016; van der Linden, Leiserowitz, Rosenthal, & Maibach, 2017). This dynamic has significant consequences for mainstream media coverage of climate change. The journalistic norm of providing balanced coverage to both sides of a debate means that contrarian voices are often given equal weight with climate scientists (Painter and Gavin, 2015). However, false-balance media coverage has been shown to decrease public perception of scientific consensus (Cook, Lewandowsky, & Ecker, 2017).

Finally, another overlooked negative impact of misinformation is its potential silencing effect. While most of the U.S. public are concerned or alarmed about climate change, less than half of segment of the population talk about the issue with friends or family (Leiserowitz et al., 2017). The main driver of this self-silencing is the misconception of pluralistic ignorance—the majority of Americans who are concerned about climate change are ignorant of the fact that they're a plurality (Geiger and Swim, 2016). This misconception is self-reinforcing, resulting in a "spiral of silence" (Maibach et al., 2016).

This chapter will explore two elements required in order to effectively counter misinformation. First, we require a stronger theoretical understanding of misinformation arguments and techniques. Second, experimental exploration of different refutation approaches are needed in order to develop evidence-based interventions. This chapter reviews research into both areas—understanding and responding to misinformation—and speculates on future lines of research.

UNDERSTANDING CLIMATE SCIENCE DENIAL

Climate change was a bipartisan issue in the 1980s, with Republican leader George H. W. Bush pledging to "fight the greenhouse effect with the White House effect" (Peterson, 1989, p. A1). However, in the early 1990s, conservative think-tanks began the process of gradually polarizing the public through misinformation campaigns (McCright and Dunlap, 2000). While contrarians rejecting the scientific consensus on climate change have branded themselves as "skeptic", this is a misleading label as genuine skepticism adopts an evidence-approach (Björnberg et al., 2017; Lewandowsky, Ballard, Oberauer, Benestad, 2016; Odenbaugh, 2016). Consequently, this chapter adopts the more accurate and

scientifically-grounded term climate science denial, or abbreviated derivations, in reference to misinformation that rejects mainstream climate science.

Conservative think-tanks (CTTs) employed a variety of strategies to disseminate their misinformation campaigns. Book publications were a key plank of early strategies, with over 90% of climate denialist books published from 1972 to 2005 produced by CTTs (Jacques, Dunlap, & Freeman, 2008). They have also exploited the journalistic norm of balanced media coverage so that denialist voices received similar amounts of media coverage to mainstream climate scientists (Painter & Ashe, 2012). They recruited a small group of contrarian scientists—the "charismatic megafauna" of climate denial (Boykoff & Olson, 2013)—to challenge the science on issues such as climate change, tobacco smoking, and acid rain (Oreskes and Conway, 2011). While contrarian scientists have published a handful of papers that rejected anthropogenic global warming (Cook et al., 2013), these papers have been shown to contain numerous methodological flaws (Abraham et al., 2014; Benestad et al., 2015).

Instead of influencing the scientific community through published research, contrarian scientists have been most impactful by promoting their viewpoints through public engagement. The normative journalist practice of giving both sides of an issue equal weight has allowed the minority of contrarians to obtain disproportionate coverage, thus amplifying their views (Boykoff & Boykoff, 2004). While the situation has improved in the U.S. prestige press (Schmid-Petri, Adam, Schmucki, & Haussler, 2015), false-balance media coverage of climate change is still problematic in U.S. network television coverage of climate change (Boykoff 2008) and the UK tabloid press (Painter and Gavin, 2015).

CTT publications in the 1990s featured three major themes—emphasizing uncertainty, extolling the benefits of global warming, and warning against the economic risks of mitigation policies (McCright and Dunlap, 2000). One of the more prolific sources of climate misinformation among CTTs has been the Heartland Institute (Boussalis and Coan, 2016), whose output is focused on delegitimizing climate science (Cann, 2015). CTT misinformation campaigns have been enabled and amplified by corporate funding (Jacques, Dunlap, and Freeman, 2008). Organizations that disseminate climate misinformation received over $900 million of corporate funding per year from 2003 to 2010 (Brulle, 2014). Conservative organizations that received corporate funding (e.g., from fossil fuel companies) escalated their output of climate misinformation compared to non-corporate funded organizations (Farrell, 2016a, 2016b). Industry funding of climate misinformation in the 1990s occurred despite the fact that the warming effects of CO2 emissions were known within the industry. (Franta, 2018). 80% of ExxonMobil's internal documents from 1977 to 1995 acknowledged that climate change was real and human-caused, while 80% of their public-facing statements from 1989 to 2004 expressed doubt (Supran and Oreskes, 2017).

Fossil fuel-funded misinformation has had an effect on public perceptions of climate change. Higher levels of CO2 emissions per capita are positively associated with lower levels of acceptance of climate change (Tranter & Booth, 2015). The association between societies dependent on fossil fuel energy and public polarization on climate change has led researchers to conclude that fossil fuel-funded misinformation has contributed to the current state of public polarization (Hornsey, Harris, & Fielding, 2018). After several decades of steady, incremental increase in polarization, the strongest drivers of attitudes about climate change are now political affiliation and political ideology (Hornsey, Harris, Bain, & Fielding, 2016). The link between climate denial and ideology varies across countries, with the strongest link found in the United States (Hornsey, Harris, & Fielding, 2018). However, climate denial is not ubiquitous among Republicans and is strongest among Tea Party members, with moderate Republicans being closer in their climate attitudes to independents (Hamilton & Saito, 2014).

The strong influence of political affiliation on climate attitudes explains why political elite cues are highly influential on public opinion. Analysis of survey data from 2002 to 2010 found that the primary driver of changes in climate attitudes were elite cues—statements from leaders of the Republican party (Brulle,

Carmichael, & Jenkins, 2012). Similarly, the drop in public acceptance of climate change in the late 2000s was found to be driven by changes in political elite cues (Mildenberger & Leiserowitz, 2017). The strong influence of political leaders on public attitudes about climate change means that cues from Republican leaders, such as the unanimous vote by Republican senators that humans aren't causing global warming (Kollipara, 2015), are likely to have a significant effect on Republican views on climate change. When Republicans hold the Congressional majority, testimonies are more likely to challenge climate science and highlight potential negative impacts of climate policy (Park, Liu, & Vedlitz, 2010).

Arguments and Techniques in Climate Misinformation

There are a variety of arguments and rhetorical strategies employed in climate misinformation, some of which are mutually contradictory (Lewandowsky, Cook, and Lloyd, 2016). Identifying and analyzing these arguments yields insights into the psychology driving climate science denial, and provides foundational frameworks that inform refutational strategies. A number of studies have attempted to categorize the various denialist arguments, examining specific aspects of the issue.

Looking at scientific themes, Rahmstorf (2004) identified three main categories of misinformation: trend (global warming isn't happening), attribution (humans aren't causing global warming), and impact (climate impacts aren't serious). Misconceptions along these three themes tend to cluster together with people holding one of the three misconceptions being more likely to hold all three (Poortinga et al., 2011). Further, skepticism about human contribution has been found to be a common source of impact and mitigation skepticism (Akter, Bennett, & Ward, 2012).

Bonds (2016) broadens the range of contrarian arguments, arguing that as well as science denialism, attitudes about policy are also important. Similarly, Capstick and Pidgeon (2013) categorized two overarching categories of climate misinformation: epistemic (related to climate science) and response (climate solutions). Mazo (2013) and Odenbaugh (2016) explored four types of climate doubt, categorising them as trend, attribution, impact, and regulation doubters.

A fifth category not included in these previous analyses includes attacks on the integrity of climate science or scientists. Arguments in this category can take various forms, including emphasis on uncertainty, attacks on scientists or scientific data/processes, casting doubt on scientific consensus, and conspiracy theories. The earliest misinformation campaigns conducted by CTTs included counter-claims questioning the scientific evidence for global warming (McCright & Dunlap, 2000). The strategy of manufacturing uncertainty has long been used by industry to cast doubt on scientific evidence regarding the harmful effects of industrial products (Dunlap & McCright, 2015; Michaels, 2008; Oreskes & Conway, 2010). Topic analysis of CTT articles identified that a major theme was scientific integrity (Boussalis and Coan, 2016). This form of implicit (uncertainty-based) misinformation has been found to be harder to correct than explicit misinformation (Rich & Zaragoza, 2015).

To synthesize these disparate content analyses, we see that climate misinformation can be summarized with five overarching categories: it's not real, it's not us, it's not bad, the experts are unreliable, and climate solutions won't work. These five denialist categories mirror the five key climate beliefs identified by psychology researchers: global warming is real, human activity is the primary cause, the impacts are bad, the experts agree on these first three points, and there's hope that we can avoid the worst impacts of climate change (Ding, Maibach, Zhao, Roser-Renouf, and Leiserowitz, 2011).

There are a variety of rhetorical techniques and logical fallacies that are employed in climate misinformation—understanding these techniques are key to countering misinformation. Ceccarelli (2011) found that the same rhetorical strategies appear in science denial across a range of topics. Similarly,

Hoofnagle (2007) and Diethelm & McKee (2009) described five techniques of science denial employed across a range of topics, including climate change, creationism, and vaccination. These five techniques are fake experts, logical fallacies, impossible expectations, cherry picking, and conspiracy theories, summarized with the acronym FLICC (Cook et al., 2015). These techniques can be deployed as deliberate deceptive strategies, or manifest as the result of psychological biases. Consequently, it is extremely difficult to distinguish between deliberate deception and genuinely held misconceptions.

Fake experts are spokespeople conveying the impression of expertise on a topic while possessing little to no relevant expertise. The most shared social media story in 2016 about climate change featured a petition of tens of thousands of science graduates, designed to cast doubt on the scientific consensus (Readfearn, 2016). This particular climate myth, originating from the Global Warming Petition Project website, is one of the most effective denialist arguments in lowering acceptance of climate change (van der Linden et al., 2017). This is despite the fact that the website employs the technique of fake experts, with only a small minority of the signatories being active researchers in climate science (Anderson, 2011).

The purpose of the fake expert strategy is to cast doubt on the high level of expert agreement on human-caused global warming—one of the most common arguments employed by opponents of climate action (Elsasser & Dunlap, 2012). This strategy dates back to 1991 when a fossil fuel group conducted a marketing campaign to "reposition global warming as theory (not fact)" (Oreskes 2010). The reasoning underlying the focus on consensus is best articulated in a political strategy memo that advised Republicans to cast doubt on consensus in order to decrease public support for climate action (Luntz, 2002). Over a decade after the Luntz memo, social scientists began publishing research identifying the powerful role that public perceptions of scientific consensus played in influencing attitudes about climate change (Cook & Lewandowsky, 2016; Ding et al., 2011; Lewandowsky et al., 2012; McCright & Dunlap, 2013; van der Linden, Leiserowitz, Feinberg, & Maibach, 2015). In light of this growing body of research, communication experts recommend that scientists communicate the consensus in order to close the consensus gap (Cook, 2016).

The fake expert strategy is not employed only as a form of deception but can also arise from motivated reasoning. People attribute greater expertise to spokespeople who articulate positions consistent with their existing beliefs and values (Kahan, Jenkins-Smith, & Braman, 2011). Consequently, contrarian scientists are more salient to people who are dismissive of climate science, leading to a distorted view of the level of scientific consensus.

Logical fallacies feature in logically flawed arguments that lead to false conclusions. Arguments can be logically flawed by committing fallacies of relevance (the premises are not relevant to the conclusion), scope (not all evidence is considered), or presumption (the argument contains false premises). Common logical fallacies are red herrings (distracting arguments that are irrelevant to the conclusion), non sequiturs (arguments where the conclusion does not follow from the premise), and false dichotomies (imposing a choice between two options, when other options or both options are viable choices). An analysis of the most common arguments against climate change found that all of the arguments contained fatal logical flaws (Cook, Ellerton, & Kinkead, 2018).

Logical fallacies can be the result of motivational biases, causing people to unintentionally present invalid arguments in support of a strongly held viewpoint (Correia, 2011). For example, the strawman fallacy is a debating strategy where an opponent's position is misrepresented in weaker form, in order to be more easily refuted. However, this can also arise because of a psychological tendency to focus on an opponent's weaker arguments while ignoring their stronger arguments (Talisse and Aikin 2006).

Impossible expectations involve a demand for unrealistic or unattainable levels of proof. The scientific method is vulnerable to this avenue of attack, as science is probabilistic by nature. The demand for

absolute scientific certainty, a technique known as the "Scientific Certainty Argumentation Method" (Freudenberg et al., 2008) is equivalent to asking for the impossible. This misleading technique can be persuasive, even in cases where there is a clear scientific consensus based on robust evidence.

The psychological bias of disconfirmation bias can lead to a demand for impossible expectations. This is the case where people vigorously oppose evidence that is perceived to threaten their pre-existing beliefs, worldview, or identity. For example, when Republicans who believed Saddam Hussein was connected to 9/11 were shown conclusive evidence that this wasn't the case, a significant proportion responded with counter-arguing and strengthened their false beliefs (Prasad, 2009).

Cherry picking involves selectively choosing data that leads to a conclusion different from the conclusion arising from all available data (Cook, Ellerton, & Kinkead, 2018). This technique is a form of paltering—rhetorical claims that are literally true but lead to false conclusions (Schauer & Zeckhauser, 2009). For example, using short-term fluctuations as evidence against a long-term trend (e.g., arguing that a few years of cooling proves global warming isn't happening) can affect attitudes about climate change (Hardy & Jamieson, 2016). However, the negative impact of paltering can be undone when the full context is provided (Lewandowsky, Ballard, Oberauer, & Benestad, 2016).

The most prominent example of this technique is the denialist argument referred to as the "pause" or "hiatus" (Boykoff, 2014). This features the argument that because of a slow-down in the warming trend around the start of the 21st Century, the long-term global warming trend had paused. However, the variations in the short-term trends were within the expected range of short-term variability—statistically, there was no evidence for a pause in global warming (Rahmstorf, Foster, & Cahill, 2017). Nevertheless, the persistent denialist talking point was internalized by the scientific community, resulting in undue focus on a non-remarkable internal fluctuation (Lewandowsky, Risbey, & Oreskes, 2016).

Conspiracy theories about climate change are common, with around 20% of the U.S. public believing that climate change is a scientific hoax (Lewandowsky et al., 2013), and a significant association between climate denial and conspiratorial thinking (Lewandowsky, Gignac, & Oberauer, 2013). When climate "naysayers" were prompted for an affective response to climate change, the most common themes were conspiratorial in nature (Smith & Leiserowitz, 2012). The dissemination of conspiracy theories result in a number of negative effects, even when people are not convinced by them. They can lower support for climate action (van der Linden, 2015), decrease one's intent to reduce one's carbon footprint (Jolley & Douglas, 2014), and decrease trust in government (Einstein & Glick, 2014). Conspiratorial thinking is self-sealing, meaning that is immune to refutation: when evidence is provided disproving a conspiracy theory, the theorist responds by broadening their conspiracy to include the source of the evidence (Lewandowsky et al., 2015).

The most prominent example of a climate conspiracy theory is "climategate", an incident in 2009 when scientists' emails were stolen and published online. Quote-mined excerpts were proposed as evidence that scientists were conspiring to falsify data and deceive the public. Nine investigations in the United States and England were conducted, with all finding no evidence of wrongdoing among scientists (Cook, 2014). There is suggestion that climategate may have contributed to a decrease in public conviction about climate change (Brisman, 2012). Nevertheless, public interest in the conspiracy waned quickly and the incident had no long-term effect on public interest (Anderegg & Goldsmith; 2014). In contrast, climate denialist blogs have intensified their interest in climategate over time (Lewandowsky, 2014).

To summate, this section provides an overview of the arguments and rhetorical techniques found in climate misinformation. Identifying these arguments and techniques are necessary in order to design appropriate interventions that neutralize the misinformation.

COUNTERING CLIMATE MISINFORMATION

Once people internalize misinformation, it is notoriously difficult to dislodge (Lewandowsky, Ecker, Seifert, Schwarz, & Cook, 2012). Even people who remember a refutation continue to be influenced by the refuted misinformation (Thorson, 2016). In more extreme situations, when a refutation is perceived to threaten a person's worldview, it can backfire and reinforce false beliefs (Hart & Nisbet, 2012). Similarly, refutations that place too much emphasis on the refuted myth increase the risk that the myth is later recalled as true (Peter & Koch, 2016).

In order to effectively refute misinformation, researchers have assembled a collection of recommended best-practices (Cook & Lewandowsky, 2011; Swire & Ecker, 2018). For example, an effective refutation requires a factual replacement that meets the causal explanations initially supplied by the refuted misinformation (Ecker et al., 2015). A refutation that mentions the myth being debunked should also warn recipients before mentioning the myth to ensure they are cognitively on guard and less likely to be influenced by the mention of the myth (Ecker et al., 2010). Refutations perceived to threaten a person's worldview are likely to be ineffective or counterproductive (Nyhan & Reifler, 2010; Prasad et al., 2009), so communication strategies are likely to be more effective if targeting audiences without ideological filters. Lastly, graphical information is more effective than text in reducing misperceptions (Nyhan & Reifler, 2018).

One approach showing a great deal of potential in countering misinformation comes from inoculation theory: a branch of psychological research that adopts the vaccination metaphor—just as biological vaccination neutralizes viruses by exposing people to a weak form of the virus, misinformation can be neutralized by exposing people to a weak form of misinformation (McGuire & Papageorgis, 1961). Inoculation is effective in neutralizing persuasive arguments across a range of issues such as health (Compton, Jackson, & Dimmock, 2016), politics (Compton & Ivanov, 2013), and climate change (Cook, Lewandowsky, & Ecker, 2017; van der Linden, Leiserowitz, Rosenthal, & Maibach, 2017).

As well as neutralizing the influence of misinformation, another benefit of inoculation is that inoculated recipients are more likely to discuss the issue—a phenomenon referred to as post-inoculation talk (Ivanov et al., 2015). This is a desired outcome with the issue of climate change which is hampered by the conundrum of "climate silence". While most Americans are alarmed or concerned about climate change, they fail to talk about the issue with family or friends (Maibach et al., 2016). One of the mechanisms driving self-censoring about climate change is the fear of looking incompetent (Geiger and Swim, 2016). Inoculation may mitigate climate silence by providing people with explanations of denialist arguments.

Structurally, inoculations consist of two elements—warning of the threat of misinformation (Banas & Richards, 2017) and counter-arguments refuting the myth. Inoculating messages can take a variety of forms while adhering to this structure. For example, fact-based inoculations neutralize misinformation by presenting recipients with facts that contradict misinforming arguments. For example, van der Linden et al. (2017) presented a number of facts about the scientific consensus and specific flaws in the Global Warming Petition Project in order to refute its argument that there is no scientific consensus.

Alternatively, logic-based inoculations explain the techniques of denial in order to boost resistance to those fallacies in general. This is an ancient approach proposed by Aristotle who argued that understanding logical fallacies was the key to a universal safeguard against misinformation (Compton, 2005). In an experiment, Cook, Lewandowsky, & Ecker (2017) explained the technique of fake experts in order to neutralize the influence of the Global Warming Petition Project, without mentioning the petition specifically. This confirms other research finding that inoculation provides an "umbrella of protection", conveying resistance to other arguments besides those mentioned in the inoculation message (Parker et

al., 2012). Critical thinking analysis offers a methodology for identifying fallacies in misinforming arguments (Cook, Ellerton, & Kinkead, 2018).

While inoculating interventions focus in large part on the recipients of misinformation, it is also possible to inoculate the sources of misinformation from disseminating misinformation in the first place. State legislators who received letters warning about the reputational risk from being fact-checked were subsequently less likely to disseminate misinformation compared to legislators who didn't receive the warning (Nyhan & Reifler, 2015).

While passive inoculation involves one-way communication of messages to an audience, active inoculation involves interactively teaching recipients to reproduce the misleading techniques of denial. For example, Roozenbeek & van der Linden (2018) employed a "fake news game" in which participants were tasked with using misleading tactics to create fake news about a strongly politicized issue, which resulted in participants being better able to identify fake news articles.

Misconception-Based Learning

Agnotology is the study of manufactured ignorance and misinformation (Proctor, 2008). Bedford (2010) operationalized this field of study in an educational context in coining the term agnotology-based learning. This involves teaching scientific concepts by examining misconceptions and how they distort the science, or by critiquing misinformation and the techniques employed to mislead. This is also known as refutational teaching (Tippett, 2010) or misconception-based learning (McCuin, Hayhoe, and Hayhoe, 2014). This teaching approach offers a powerful and practical way to apply inoculation in an educational setting.

In misconception-based lessons, misconceptions are first activated then immediately countered with accurate information or inoculating refutations. In contrast, standard lessons teach accurate information without any reference to the misconceptions. Misconception-based learning has been found to be one of the most powerful ways of teaching science, and offer a number of benefits over standard lessons. It has been found to be more effective than standard lessons, producing stronger and longer lasting learning gains (McCuin et al., 2014). Students find this type of lesson more engaging (Mason et al., 2008), emerging with improved argumentative and critical thinking skills (Kuhn & Crowell, 2011; Todd & O'Brien, 2016).

Based on this research, researchers encourage teachers to incorporate curriculum that address pedagogical gaps and student misconceptions about climate change (Frankie, 2014). Until recent times, there has been a dearth of educational resources that explicitly address misconceptions and misinformation (Tippett, 2010). However, this oversight is beginning to be addressed, and teachers are now applying misconception-based lessons in their classrooms (Bedford, 2010; Cook, Bedford, & Mandia, 2014; Lambert & Bleicher, 2017; Lovitt & Shuyler, 2016). A textbook on climate change explicitly adopts a misconception-based learning approach, with each chapter adhering to a fact-myth-fallacy structure (Bedford & Cook, 2016). Similarly, a Massive Open Online Course (MOOC) on climate science denial, which refutes 50 of the most common myths about climate change using a misconception-based learning approach, has reached over 40,000 students from 185 countries (Cook et al., 2015).

One important element of misconception-based learning is that it extends beyond the typical skills taught to convey information literacy such as assessing source credibility. Yang (2017) argues that misinforming sources have hijacked the standard cues for credibility, making it more difficult for students to evaluate sources. Consequently, the risk in teaching information literacy is that people may become more cynical and distrustful of media in general (Mihailidis & Viotty, 2017). Consequently, more rigorous critical

thinking and the ability to assess weak arguments are essential skills as students navigate the current media environment.

Technocognition

Social media outlets such as Twitter and Facebook have exacerbated the problem of misinformation (Shao et al., 2018), facilitating the spread of misinformation on science topics (Bessi et al., 2015; del Vicario et al., 2017). Low quality information is just as or more likely to go viral as high quality information (Qiu, Oliveira, Shirazi, Flammini, & Menczer, 2017; Weng, Flammini, Vespignani, & Menczer, 2012). The structural and social features of social media have facilitated the development of echo chambers, where users are mostly exposed to viewpoints they already agree with (Jasny, Waggle, & Fisher, 2015). This dynamic accelerates public polarization, and causes people to be more resistant to changing their beliefs (Leviston et al., 2013).

Blogs have also been a prolific source of misinformation about climate change, employing a range of arguments (such as downplaying polar bear vulnerability) in order to cast doubt on the broader impacts of climate change (Harvey et al., 2017). Comment threads on blogs are commonly political in nature, arguing that climate science is illegitimate, politicized, unreliable, and corrupted by conspiracy (Matthews, 2015). Twitter has also been a fertile ground for denialist themes—in the aftermath of Hurricane Sandy in 2012, a major theme in Twitter threads was that climate science was a conspiracy designed to increase the size of government (Jacques & Knox, 2016).

However, social media also offers opportunities to correct the negative influence of misinformation. It is possible for heterogeneous relationships to form on social media platforms, allowing people to encounter contrary views (Kim, Chen, & gil de Zuniga, 2013; Kim & Chen, 2016). This allows the opportunity to counter misinformation with corrections through social networks (Bode & Vraga, 2015; Margolin et al., 2018; Vraga & Bode, 2017). Technology can also be harnessed to deploy timely corrections through social networks. However, there are potential pitfalls to employing technological solutions in a refutational context.

There have been attempts to implement fact-checking interventions on social media platforms that have backfired. When Facebook began labelling misinformation as "fake news", the result was an increase in shares of the misinformation (Levin, 2017). When refutations are posted in response to Facebook posts, conspiratorial users increase their engagement with conspiratorial posts (Zollo et al., 2017). There is also a risk that providing general warnings about fake news will increase cynicism, leading to a decrease in belief in news articles in general (Pennycook and Rand, 2017; van Duyn and Collier, 2017).

These unintended backfire effects underscore the importance of incorporating into technological solutions the best-practices informed by psychological research. This interdisciplinary approach is known as technocognition (Lewandowsky, Ecker, & Cook, 2017)—the combination of psychology, critical thinking, communication, and behavioural economics in the design of scalable, technological solutions.

Potentially the most impactful application of technocognition is the "holy grail of fact-checking"—computer-assisted detection and assessment of the veracity of misinformation (Hassan et al., 2015). There have been a number of attempts to automatically detect misinformation using a variety of algorithms with varying degrees of success. Browser extensions tag the veracity of Facebook links based on their credibility (Itkowitz, 2016; Oremus, 2016). Ciampaglia et al. (2015) used data from Wikipedia to assess the truth value of declarative statements. By scanning for cognitive, psychological, and emotional linguistic patterns, machines can detect deceptive content more reliably than most human judges (Ott, Choi, Cardie, & Hancock, 2011).

Researchers have already applied automatic machine learning (i.e., not employing any human training) to conduct topic analysis of climate misinformation, identifying the major themes in thousands of conservative think-tank articles (Boussalis and Coan, 2016). Further, the static nature of climate science denial, with the same arguments from the 1990s recurring to this day (McCright and Dunlap, 2000), presents a unique opportunity for researchers seeking methods to automatically detect specific claims in climate misinformation. This means a vast corpus of data exists that can be used to train a machine to detect consistent textual patterns. This would enable researchers to construct a detailed history of denialist claims appearing in a variety of outlets such as mainstream media, social media, fossil fuel industry publications, and Congressional statements, as well as identification and refutation of misinformation in real-time.

FUTURE RESEARCH DIRECTIONS

Cultural values, individual cognition, societal trends, developing technology, and a changing media landscape all contribute to the multi-faceted problem of misinformation. Countering misinformation requires a multi-disciplinary approach, involving the synthesis of the findings of social, political, information, computer, and psychological science in integrated, holistic solutions.

Existing research has deconstructed deductive misinformation—arguments with definitive conclusions (Cook, Ellerton, & Kinkead, 2018). However, further research is required in exploring other forms of misinformation. First, inductive misinformation with probabilistic conclusions is understudied—which is problematic given the long history of emphasis on uncertainty in climate misinformation campaigns and the difficulty in countering this form of misinformation (Rich & Zaragoza, 2015). Second, while there is much research into character attacks designed to reduce the credibility of individuals or groups (Shiraev, 2008), this research discipline has not yet turned its attention to climate misinformation. Potentially, the existing literature on image repair strategies may provide remedial interventions to restore public trust in climate scientists (Benoit, 1995). Third, paltering is a misinformation technique that uses literally true but misleading claims (Schauer & Zeckhauser, 2009). Computer-assisted detection of these more subtle forms of misinformation are likely to be challenging tasks, and thus countering them will likely require human-sourced refutation and critical thinking education.

Ideology is a powerful force in preventing refutations from taking effect. However, there are suggestions that counter-attitudinal retractions can be effective under certain conditions (Ecker, Lewandowsky, Fenton, & Martin, 2013; Hyman & Jalbert, 2017). Inoculations that emphasise how the recipient has been misled have been observed to be effective across the political spectrum (Cook, Lewandowsky, & Ecker, 2017). Reframing climate messages using moral values that are valued by conservatives (e.g., purity) has been shown to neutralize ideological influence (Feinberg & Willer, 2013). Other possible framings include the public health impacts of climate change (Maibach, Nisbet, Baldwin, Akerlof, & Diao, 2010) and the relative costs of mitigation vs. future impacts (Hurlstone, Lewandowsky, Newell, & Sewell, 2014). There is also conflicting findings on how worldview interacts with misinformation, with some studies finding conservatives are more susceptible to misinformation than liberals (Lewandowsky & Oberauer, 2016; Pfattheicher and Schindler, 2016) and other research finding the opposite (Bakshy, Messing, & Adamic, 2015). Future studies should seek to develop better understanding how ideology interacts with misinformation and refutations, and whether this influence can be reduced through different framings.

Further research is required on exploring the relative efficacy of different refutation approaches. Factors such as platform (e.g., Twitter, Facebook, and mainstream media fact-check), timing (pre-emptive inoculation vs reactive refutation), format (text-only vs visual), type of misinformation (e.g., deductive, inductive, character attacks, and paltering), focus of refutation (factual, logic-based, source-credibility),

and issue (e.g., climate change, vaccination, other science issues) can all be experimentally manipulated in order to develop best-practices recommendations for communicators and educators.

From a technocognition perspective, exploring refutational interventions in a social media context is of vital importance. Identifying the conditions under which flagging of fake news is beneficial versus counterproductive will provide much-needed guidance for practitioners, given the potential for interventions to backfire (Garrett & Weeks, 2013; Levin, 2017). Research advancements on refutational approaches (Paynter et al., 2019) could be combined with computer science research into detection of misinformation to develop more sophisticated and accurate tools, implemented across a range of different social media outlets. These might take the form of browser extensions (Oremus, 2016), interactive websites, Twitter-scripts, or annotated search results. Subsequent research should measure the effectiveness of these tools across different audiences, issues, and platforms. In particular, keeping up with the proliferation of ever-evolving social media channels will be challenging for manual and automated fact-checkers (Babaker & Moy, 2016).

More generally, interdisciplinary integration of psychology with computer science is an exciting new area of research with potential practical application in the area of climate misinformation. Social network analysis simulates how misinformation spreads through a social network in the same way that disease spreads through a population. This allows researchers to explore possible interventions to prevent dissemination. For example, by computing the most influential nodes in a network, researchers can identify the most effective ways to block negative influences (Nguyen et al., 2012). By considering the cultural values of nodes in a social network, social network analysis can simulate how culturally relevant information (or misinformation) disseminates through a network (Yeaman, Schick, & Lehmann, 2012). By implementing inoculating interventions at sufficient scale, it may be possible to achieve herd immunity in a network, thus eradicating specific strains of misinformation (Tambuscio et al., 2015).

Underscoring this research into public opinions and misinformation is the grim reality that there is little relationship between U.S. public opinion on issues and subsequent policy outcomes (Gilens & Page, 2014). Instead, there is a much stronger relationship between economic elite opinion and policy outcomes. One plausible disconnect is misconceptions about public opinion held by Congressional staffers, whose perceptions are driven more by their contact with business and ideologically conservative groups (Hertel-Fernandez, Mildenberger, & Stokes, 2017). Further research is needed to tease out the causes of the disconnect between public opinion and policy outcomes in democratic societies, and explore ways to close these disconnects.

CONCLUSION

Misinformation as an issue has become especially salient in recent years. However, climate misinformation is not a new phenomenon (Krugman, 2018), with decades of research shedding light onto how to understand and counter misinformation. The finding that misinformation cancels out accurate information implies that science communication is a necessary but insufficient condition for communicators and educators seeking to raise public levels of climate literacy. While it is imperative that we address the influence of misinformation, research also finds that poorly designed interventions can be ineffective or counterproductive. Therefore, it is recommended that educators and communicators adopt refutational practices informed by psychological research findings.

Inoculation has been identified as an effective method of neutralizing misinformation. This approach can be implemented through educational efforts, public communication campaigns, and technological applications on social media. By combining scientific content with inoculating refutations, we can increase science literacy levels and foster critical thinking skills. Inoculating campaigns, if implemented

widely enough in classrooms, on social media, and in mainstream media outlets, could potentially eradicate climate science denial.

To conclude, misinformation is a vast and complicated societal problem, that requires robust, holistic solutions. Technological solutions deployed through social media and educational curriculum that explicitly address misinformation are two interventions with the potential to inoculate the public against misinformation. It is only through multi-disciplinary collaborations, uniting psychology, computer science, and critical thinking researchers, that ambitious, innovative solutions can be developed at scales commensurate with the scale of misinformation efforts.

REFERENCES

Abraham, J. P., Cook, J., Fasullo, J. T., Jacobs, P. H., Mandia, S. A., & Nuccitelli, D. A. (2014). Review of the consensus and asymmetric quality of research on human-induced climate change. *Cosmopolis*, *1*, 3-18.

Akter, Sonia, Jeff Bennett, & Michael B. Ward. (2012). "Climate Change Scepticism and Public Support for Mitigation: Evidence from an Australian Choice Experiment." *Global Environmental Change*, *22*(3), 736 - 745.

Anderegg, W. R., & Goldsmith, G. R. (2014). Public interest in climate change over the past decade and the effects of the 'climategate' media event. *Environmental Research Letters*, *9*(5), 054005.

Anderson, E. (2011). Democracy, public policy, and lay assessments of scientific testimony. *Episteme*, *8*, 534 144–164.

Babaker, M., & Moy, W. (2016). The State of Automated Fact checking. *FullFact.org*. Retrieved from https://fullfact.org/media/uploads/full_fact-the_state_of_automated_factchecking_aug_2016.pdf

Bakshy, E., Messing, S., & Adamic, L. A. (2015). Exposure to ideologically diverse news and opinion on Facebook. *Science*, *348*(6239), 1130-1132.

Banas, J. A., & Richards, A. S. (2017). Apprehension or motivation to defend attitudes? Exploring the underlying threat mechanism in inoculation-induced resistance to persuasion. *Communication Monographs*, *84*(2), 164-178.

Bedford, D. (2010). Agnotology as a teaching tool: Learning climate science by studying misinformation. *Journal of Geography*, *109*(4), 159-165.

Bedford, D., & Cook, J. (2016). *Climate Change: Examining the Facts*. Santa Barbara, CA: ABC-CLIO.

Benestad, R. E., Nuccitelli, D., Lewandowsky, S., Hayhoe, K., Hygen, H. O., van Dorland, R., & Cook, J. (2015). Learning from mistakes in climate research. *Theoretical and Applied Climatology*, 1-5.

Benoit, W. L. (1995). *Accounts, Excuses, Apologies: A Theory of Image Restoration Strategies*. Albany: State University of New York Press.

Bessi, A., Coletto, M., Davidescu, G. A., Scala, A., Caldarelli, G., & Quattrociocchi, W. (2015). Science vs conspiracy: Collective narratives in the age of misinformation. *PloS one*, *10*(2), e0118093.

Björnberg, K. E., Karlsson, M., Gilek, M., & Hansson, S. O. (2017). Climate and environmental science denial: A review of the scientific literature published in 1990–2015. *Journal of Cleaner Production*, doi: 10.1016/j.jclepro.2017.08.066.

Bode, L., & Vraga, E. K. (2015). In related news, that was wrong: The correction of misinformation through related stories functionality in social media. *Journal of Communication*, *65*(4), 619-638.

Bolsen, T., & Druckman, J. N. (2015). Counteracting the politicization of science. *Journal of Communication*, *65*(5), 745-769.

Bonds, E. (2016). Beyond Denialism: Think Tank Approaches to Climate Change. *Sociology Compass*, *10*(4), 306-317.

Boussalis, C., & Coan, T. G. (2016). Text-mining the signals of climate change doubt. *Global Environmental Change*, *36*, 89-100.

Boykoff, M.T., (2008), Lost in translation? United States television news coverage of anthropogenic climate change, 1995–2004. *Climatic Change*, 86 (1), 1–11.

Boykoff, M. T. (2014). Media discourse on the climate slowdown. *Nature Climate Change*, *4*, 156-158.

Boykoff, M. T., & Boykoff, J. M. (2004). Balance as bias: global warming and the US prestige press. *Global Environmental Change*, *14*(2), 125-136.

Boykoff, M. T., & Olson, S. K. (2013). 'Wise contrarians': a keystone species in contemporary climate science, politics and policy. *Celebrity studies*, *4*(3), 276-291.

Brisman, A. (2012). The cultural silence of climate change contrarianism. In R. White (Ed.), *Climate change from a criminological perspective* (pp. 41–70). New York: Springer.

Brulle, R. J. (2014). Institutionalizing delay: foundation funding and the creation of US climate change counter-movement organizations. *Climatic Change*, *122*(4), 681-694.

Brulle, R. J., Carmichael, J., & Jenkins, J. C. (2012). Shifting public opinion on climate change: An empirical assessment of factors influencing concern over climate change in the U.S., 2002–2010. *Climatic Change*, *114*, 169–188.

Cann, H. W. (2015). Climate Change, Still Challenged: Conservative Think Tanks and Skeptic Frames. Presented at the *Annual Meeting of the Western Political Science Association Las Vegas*, April 2–4, 2015.

Capstick, S. B., & Pidgeon, N. F. (2014). What is climate change scepticism? Examination of the concept using a mixed methods study of the UK public. *Global Environmental Change*, *24*, 389-401.

Ceccarelli, L. (2011). Manufactured scientific controversy: Science, rhetoric, and public debate. *Rhetoric & Public Affairs*, *14*(2), 195-228.

Ciampaglia, G. L., Shiralkar, P., Rocha, L. M., Bollen, J., Menczer, F., & Flammini, A. (2015). Computational fact checking from knowledge networks. *PLoS ONE*, *10*, 1-13.

Compton, J. (2005). Comparison, contrast, and synthesis of Aristotelian rationality and inoculation. *Journal of the Speech and Theatre Association of Missouri*, *35*, 1-23.

Compton, J., & Ivanov, B. (2013). Vaccinating voters: Surveying political campaign inoculation scholarship. In *E. L. Cohen (Ed.), Communication yearbook 37* (pp. 250-283). New York, NY: Routledge.

Compton, J., Jackson, B., & Dimmock, J. A. (2016). Persuading others to avoid persuasion: Inoculation theory and resistant health attitudes. *Frontiers in Psychology*, *7*, 122.

Cook, J. (2014). What do the 'Climategate' hacked CRU emails tell us? *Skeptical Science*. Retrieved from https://skepticalscience.com/archive.php?r=909

Cook, J. (2016). Countering Climate Science Denial and Communicating Scientific Consensus. *Oxford Encyclopedia of Climate Change Communication*. London: Oxford University Press.

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.

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

Cook, J. & Lewandowsky, S. (2016). Rational Irrationality: Modeling Climate Change Belief Polarization Using Bayesian Networks. *Topics in Cognitive Science*, *8*(1), 160-179.

Cook, J., & Lewandowsky, S. (2011). *The Debunking Handbook*. St. Lucia, Australia: University of Queensland. ISBN 978-0-646-56812-6. [available at http://sks.to/debunk].

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

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

Cook, J., Schuennemann, K., Nuccitelli, D., Jacobs, P., Cowtan, K., Green, S., Way, R., Richardson, M., Cawley, G., Mandia, S., Skuce, A., & Bedford, D. (April 2015). Denial101x: Making Sense of Climate Science Denial. *edX*. http://edx.org/understanding-climate-denial

Correia, V. (2011). Biases and fallacies: The role of motivated irrationality in fallacious reasoning. *Cogency*, *3*(1), 107-126.

Del Vicario, M., Bessi, A., Zollo, F., Petroni, F., Scala, A., Caldareli, G., Stanley, H. E., & Quattrociocchi, W. (2017). The spreading of misinformation online. *Proceedings of the National Academy of Sciences*, *113*, 554-559.

Diethelm, P., & McKee, M. (2009). Denialism: what is it and how should scientists respond? *The European Journal of Public Health*, *19*(1), 2-4.

Ding, D., Maibach, E. W., Zhao, X., Roser-Renouf, C., & Leiserowitz, A. (2011). Support for climate policy and societal action are linked to perceptions about scientific agreement. *Nature Climate Change*, *1*(9), 462.

Douglas, K. M., & Sutton, R. M. (2008). The hidden impact of conspiracy theories: Perceived and actual influence of theories surrounding the death of Princess Diana. *The Journal of Social Psychology*, *148*(2), 210-222.

Dunlap, R. E., & McCright, A. M. (2015). Challenging climate change: The denial countermovement. In Riley E. Dunlap & Robert J. Brulle (Eds.), *Climate change and society: Sociological perspective*s, (pp. 300-322). New York: Oxford University Press.

Dunlap, R. E., McCright, A. M., & Yarosh, J. H. (2016). The Political Divide on Climate Change: Partisan Polarization Widens in the US. *Environment: Science and Policy for Sustainable Development*, *58*(5), 4-23.

Ecker, U. K. H., Lewandowsky, S., Cheung, C. S. C., & Maybery, M. T. (2015). He did it! She did it! No, she did not! Multiple causal explanations and the continued influence of misinformation. *Journal of Memory and Language*, *85*,101–115.

Ecker, U. K., Lewandowsky, S., Fenton, O., & Martin, K. (2014). Do people keep believing because they want to? Preexisting attitudes and the continued influence of misinformation. *Memory & Cognition*, *42*(2), 292-304.

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

Einstein, K. L., & Glick, D. M. (2014). Do I think BLS data are BS? The consequences of conspiracy theories. *Political Behavior*, *37*(3), 679-701.
Farrell, J. (2016a). Corporate funding and ideological polarization about climate change. *Proceedings of the National Academy of Sciences*, *113*(1), 92-97.

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

Farrell, J. (2016a). Corporate funding and ideological polarization about climate change. *Proceedings of the National Academy of Sciences*, *113*(1), 92-97.

Farrell, J. (2016b). Network structure and influence of the climate change counter-movement. *Nature Climate Change*, *6*(4), 370-374.

Feinberg, M., & Willer, R. (2013). The moral roots of environmental attitudes. *Psychological science*, *24*(1), 56-62.

Frankie, Thomas J., "Facing the Controversy: A Grounded Theory Study of How Teachers Plan to Address Climate Change in Their Classrooms" (2014). Education Doctoral. Paper 191.

Franta, B. (2018). Early oil industry knowledge of CO 2 and global warming. *Nature Climate Change*, 1.

Freudenburg, W. R., Gramling, R., & Davidson, D. J. (2008). Scientific certainty argumentation methods (SCAMs): science and the politics of doubt. *Sociological Inquiry*, *78*(1), 2-38.

Garrett, R.K., & Weeks, B.E. (2013, February). The promise and peril of real-time corrections to political misperceptions. In *Proceedings of the 2013 conference on Computer supported cooperative work* (pp. 1047-1058). ACM.

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

Gilens, M., & Page, B. I. (2014). Testing theories of American politics: Elites, interest groups, and average citizens. *Perspectives on Politics*, *12*, 564–581.

Hamilton, L. C., & Saito, K. (2015). A four-party view of US environmental concern. *Environmental Politics*, *24*(2), 212-227.

Hardy, B. W., & Jamieson, K. H. (2016). Overcoming endpoint bias in climate change communication: the case of Arctic sea ice trends. *Environmental Communication*, 1-13.

Hart, P. S., & Nisbet, E. C. (2011). Boomerang effects in science communication: How motivated reasoning and identity cues amplify opinion polarization about climate mitigation policies. *Communication Research*, *39*(6), 701–723.

Hassan, N., Adair, B., Hamilton, J. T., Li, C., Tremayne, M., Yang, J., & Yu, C. (2015). The quest to automate fact-checking. *Proceedings of the 2015 Computation+Journalism Symposium*.

Hertel-Fernandez, A., Mildenberger, M., & Stokes, L. C. (2017). Legislative Staff and Representation in Congress. *American Political Science Review*, 1-18.

Hoofnagle, M. (2007, April 30). Hello Scienceblogs. *Denialism Blog*. Retrieved from http://scienceblogs.com/denialism/about/

Hornsey, M. J., Harris, E. A., Bain, P. G., & Fielding, K. S. (2016). Meta-analyses of the determinants and outcomes of belief in climate change. *Nature Climate Change*, *6*(6), 622-626.

Hornsey, M. J., Harris, E. A., & Fielding, K. S. (2018). Relationships among conspiratorial beliefs, conservatism and climate scepticism across nations. *Nature Climate Change*, 1.

Houghton JT, Meira Filho LG, Callander BA, Harris N, Kattenberg A, Maskell K (eds) (1996) *Climate change 1995: the science of climate change – contribution of working group I to the second assessment report of the intergovernmental panel on climate change*. Cambridge University Press, Cambridge, UK.

Hurlstone, M. J., Lewandowsky, S., Newell, B. R., & Sewell, B. (2014). The effect of framing and normative messages in building support for climate policies. *PLOS ONE*, *9*, e114335.

Hyman, I. E., & Jalbert, M. C. (2017). Misinformation and worldviews in the post-truth information age: Commentary on Lewandowsky, Ecker, and Cook. *Journal of Applied Research in Memory and Cognition*, *6*, 377–381.

Itkowitz, C. (2016, Nov 20). Fake news is a real problem. These college students came up with a fix. *Washington Post*. Retrieved from http://www.chicagotribune.com/bluesky/technology/ct-fake-news-college-students-fix-wp-bsi-20161120-story.html

Ivanov, B., Sims, J. D., Compton, J., Miller, C. H., Parker, K. A., Parker, J. L., Harrison, K., & Averbeck, J. M. (2015). The General Content of Postinoculation Talk: Recalled Issue-Specific Conversations Following Inoculation Treatments. *Western Journal of Communication*, *79*(2), 218-238.

Jacques, P. J., Dunlap, R. E., & Freeman, M. (2008). The organisation of denial: Conservative think tanks and environmental scepticism. *Environmental politics*, *17*(3), 349-385.

Jacques, P. J., & Knox, C. C. (2016). Hurricanes and hegemony: A qualitative analysis of micro-level climate change denial discourses. *Environmental Politics*, 1-22.

Jasny, L., Waggle, J., & Fisher, D. R. (2015). An empirical examination of echo chambers in US climate policy networks. *Nature Climate Change*, *5*(8), 782-786.

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

Kim, Y., & Chen, H. T. (2016). Social media and online political participation: The mediating role of exposure to cross-cutting and like-minded perspectives. *Telematics and Informatics*, *33*(2), 320-330.

Kim, Y., Chen, H. T., & gil de Zúñiga, H. (2013). Stumbling upon news on the Internet: Effects of incidental news exposure and relative entertainment use on political engagement. *Computers in Human Behavior*, *29*(6), 2607-2614.

Kollipara, P. (Jan. 21, 2015). Wrap-up: U.S. Senate agrees climate change is real—but not necessarily that humans are causing it. *Science*. Retrieved from http://www.sciencemag.org/news/2015/01/wrap-us-senate-agrees-climate-change-real-not-necessarily-humans-are-causing-it

Krugman, P (2018, December). Climate Denial Was the Crucible for Trumpism. New York Times. Available at https://www.nytimes.com/2018/12/03/opinion/climate-denial-trump-gop.html

Kuhn, D., & Crowell, A. (2011). Dialogic argumentation as a vehicle for developing young adolescents' thinking. *Psychological Science*, *22*(4), 545-552.

Lambert, J. L., & Bleicher, R. E. (2017). Argumentation as a strategy for increasing preservice teachers' understanding of climate change, a key global socioscientific issue. *International Journal of Education in Mathematics, Science and Technology*, *5*(1), 101-112.

Leiserowitz, A., Maibach, E., Roser-Renouf, C., Rosenthal, S., & Cutler, M. (2017). *Climate change in the American mind: May 2017*. Yale University and George Mason University. New Haven, CT: Yale Program on Climate Change Communication.

Levin, S. (2017, May 16). Facebook promised to tackle fake news. But the evidence shows it's not working. *The Guardian*. Retrieved from https://www.theguardian.com/technology/2017/may/16/facebook-fake-news-tools-not-working

Leviston, Z., Walker, I., & Morwinski, S. (2013). Your opinion on climate change might not be as common as you think. *Nature Climate Change*, *3*(4), 334.

Lewandowsky, S. (2014). Conspiratory fascination versus public interest: the case of 'climategate'. *Environmental Research Letters*, 9(11), 111004.

Lewandowsky, S., Ballard, T., Oberauer, K., & Benestad, R. (2016). A blind expert test of contrarian claims about climate data. *Global Environmental Change*, *39*, 91–97.

Lewandowsky, S., Cook, J., & Lloyd, E. (2016). The 'Alice in Wonderland' mechanics of the rejection of (climate) science: simulating coherence by conspiracism. *Synthese*, 1-22.

Lewandowsky, S., Cook, J., Oberauer, K., Brophy, S., Lloyd, E. A., & Marriott, M. (2015). Recurrent fury: Conspiratorial discourse in the blogosphere triggered by research on the role of conspiracist ideation in climate denial. *Journal of Social and Political Psychology*, *3*(1), 142-178.

Lewandowsky, S., Ecker, U. K., & Cook, J. (2017). Beyond misinformation: Understanding and coping with the "post-truth" era. *Journal of Applied Research in Memory and Cognition*, *6*(4), 353-369.

Lewandowsky, S., Ecker, U. K., Seifert, C. M., Schwarz, N., & Cook, J. (2012). Misinformation and its correction continued influence and successful debiasing. *Psychological Science in the Public Interest*, *13*(3), 106-131.

Lewandowsky, S., Gignac, G. E., & Oberauer, K. (2013). The role of conspiracist ideation and worldviews in predicting rejection of science. *PloS One*, *8*(10), e75637.

Lewandowsky, S., Gignac, G. E., & Vaughan, S. (2013). The pivotal role of perceived scientific consensus in acceptance of science. *Nature Climate Change*, *3*(4), 399-404.

Lewandowsky, S., & Oberauer, K. (2016). Motivated rejection of science. *Current Directions in Psychological Science*, *25*, 217–222.

Lewandowsky, S., Risbey, J. S., & Oreskes, N. (2016). The "pause" in global warming: Turning a routine fluctuation into a problem for science. *Bulletin of the American Meteorological Society*, *97*(5), 723-733.

Lovitt, C. F., & Shuyler, K. (2016). Teaching Climate Change Concepts and the Nature of Science: A Library Activity To Identify Sources of Climate Change Misconceptions. In *Integrating Information Literacy into the Chemistry Curriculum* (pp. 221-246). American Chemical Society.

Luntz, F. (2002) The environment: a cleaner, safer, healthier America. *Luntz Research*, Alexandria. Retrieved from https://www2.bc.edu/~plater/Newpublicsite06/suppmats/02.6.pdf

Maibach, E., Leiserowitz, A., Rosenthal, S., Roser-Renouf, C., & Cutler, M. (2016). Is there a climate "spiral of silence" in America: March, 2016. *Yale University and George Mason University*. New Haven, CT: Yale Program on Climate Change Communication.

Maibach, E., Nisbet, M., Baldwin, P., Akerlof, K., & Diao, G. (2010). Reframing climate change as a public health issue: An exploratory study of public reactions. *BMC Public Health*, *10*, 299.

Margolin, D. B., Hannak, A., & Weber, I. (2018). Political fact-checking on Twitter: when do corrections have an effect? *Political Communication*, *35*(2), 196-219.

Marsh, E. J., & Yang, B. W. (2017). A call to think broadly about information literacy: Comment on "beyond misinformation: Understanding and coping with the post-truth era" by Lewandowsky, Ecker, and Cook. *Journal of Applied Research in Memory and Cognition*, *6*, 401–404.

Mason, L., Gava, M., & Boldrin, A. (2008). On warm conceptual change: The interplay of text, epistemological beliefs, and topic interest. *Journal of Educational Psychology*, *100*(2), 291.

Matthews, P. (2015). Why Are People Skeptical about Climate Change? Some Insights from Blog Comments. *Environmental Communication*, 9(2), 153-168.

Mazo, J. (2013). Climate change: strategies of denial. *Survival*, *55*(4), 41-49.

McCright, A. M., Charters, M., Dentzman, K., & Dietz, T. (2016). Examining the Effectiveness of Climate Change Frames in the Face of a Climate Change Denial Counter-Frame. *Topics in Cognitive Science*, *8*(1), 76-97.

McCright, A. M., & Dunlap, R. E. (2000). Challenging global warming as a social problem: An analysis of the conservative movement's counter-claims. *Social problems*, *47*(4), 499-522.

McCright, A. M., Dunlap, R. E., & Xiao, C. (2013). Perceived scientific agreement and support for government action on climate change in the USA. *Climatic Change*, *119*(2), 511-518.

McCuin, J. L., Hayhoe, K., & Hayhoe, D. (2014). Comparing the Effects of Traditional vs. Misconceptions-Based Instruction on Student Understanding of the Greenhouse Effect. *Journal of Geoscience Education*, *62*(3), 445-459.

McGuire, W. J., & Papageorgis, D. (1961). The relative efficacy of various types of prior belief-defense in producing immunity against persuasion. *Public Opinion Quarterly*, *26*, 24-34.

Mihailidis, P., & Viotty, S. (2017). Spreadable spectacle in digital culture: Civic expression, fake news, and the role of media literacies in post-fact society. *American Behavioral Scientist*, 61, 441–454.

Mildenberger, M., & Leiserowitz, A. (2017). Public opinion on climate change: Is there an economy–environment tradeoff? *Environmental Politics*, 1-24.

Nguyen, T.H., Tsai, J., Jiang, A., Bowring, E., Maheswaran, R., & Tambe, M. (2012). Security Games on Social Networks. In *2012 AAAI Fall Symposium Series*.

Nyhan, B., & Reifler, J. (2010). When Corrections Fail: The persistence of political misperceptions. *Political Behavior*. *32*(2): 303–330. doi:10.1007/s11109-010-9112-2

Nyhan, B., & Reifler, J. (2015). The effect of fact-checking on elites: A field experiment on U.S. state legislators. *American Journal of Political Science*, *59*, 628–640.

Nyhan, B., & Reifler, J. (2018). The roles of information deficits and identity threat in the prevalence of misperceptions. *Journal of Elections, Public Opinion and Parties*, 1-23.

Odenbaugh, J. (2017). On the Contrary: How to Think About Climate Skepticism. Routledge Companion to Environmental Ethics, Benjamin Hale and Andrew Light, eds. Routledge Press. https://static1.squarespace.com/static/5224f8d1e4b02f25c1dde748/t/55a459d9e4b093eb2b4e5297/1436834265882/Odenbaugh+On+the+Contrary.pdf

Oremus, W. (2016). Only You Can Stop the Spread of Fake News. *Slate*. Available at http://www.slate.com/articles/technology/technology/2016/12/introducing_this_is_fake_slate_s_tool_for_stopping_fake_news_on_facebook.html

Oreskes, N. (2010) My facts are better than your facts,: spreading good news about global warming, in: M. S. Morgan and P. Howlett (eds.) *How do facts travel?* (Cambridge: Cambridge University Press), pp. 135–166.

Oreskes, N., & Conway, E. M. (2010). *Merchants of doubt: How a handful of scientists obscured the truth on issues from tobacco smoke to global warming*. Bloomsbury Publishing, USA.

Ott, M., Choi, Y., Cardie, C. and Hancock, J.T. (2011). Finding deceptive opinion spam by any stretch of the imagination. In *Proceedings of the 49th Annual Meeting of the Association for Computational Linguistics: Human Language Technologies – Volume 1*, Association for Computational Linguistics, 309-319.

Painter, J., & Ashe, T. (2012). Cross-national comparison of the presence of climate scepticism in the print media in six countries, 2007–10. *Environmental Research Letters*, *7*(4), 044005.

Painter, J., & Gavin, N. T. (2015). Climate Skepticism in British Newspapers, 2007–2011. *Environmental Communication*, 1-21.

Park, H. S., Liu, X., & Vedlitz, A. (2010). *Framing climate policy debates: Science, network, and US Congress, 1976–2007* (Conference proceedings of the Policy Networks Conference 2010). Retrieved from http://opensiuc.lib.siu.edu/pnconfs_2010/41

Parker, K. A., Ivanov, B., & Compton, J. (2012). Inoculation's efficacy with young adults' risky behaviors: can inoculation confer cross-protection over related but untreated issues? *Health communication*, *27*(3), 223-233.

Paynter, J., Luskin-Saxby, S., Keen, D., Fordyce, K., Frost, G., Imms, C., Miller, S., Trembath, D.,Tucker, M., & Ecker, U. (2019). Evaluation of a Template for Countering Misinformation—Real-world Autism Treatment Myth Debunking. *PLOS One*, *14*(1): e0210746.

Pennycook, G., & Rand, D. G. (2017). Assessing the Effect of "Disputed" Warnings and Source Salience on Perceptions of Fake News Accuracy. *SSRN*. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3035384

Peter, C., & Koch, T. (2016). When debunking scientific myths fails (and when it does not): The backfire effect in the context of journalistic coverage and immediate judgments as prevention strategy. *Science Communication*, *38*,3–25.

Peterson, C. (1989, May 9). Experts, OMB spar on global warming: "Greenhouse Effect" may be accelerating, scientists tell hearing. *Washington Post*, A1.

Pfattheicher, S., & Schindler, S. (2016). Misperceiving bull-shit as profound is associated with favorable views of Cruz,Rubio, Trump and conservatism. *PLOS ONE*, *11*, e0153419.

Plutzer, E., McCaffrey, M., Hannah, A. L., Rosenau, J., Berbeco, M., & Reid, A. H. (2016). Climate confusion among U.S. teachers. *Science*, *351*(6274), 664-665.

Poortinga, W., Spence, A., Whitmarsh, L., Capstick, S., & Pidgeon, N. F. (2011). Uncertain climate: An investigation into public scepticism about anthropogenic climate change. *Global Environmental Change*, *21*(3), 1015-1024.

Prasad, M., Perrin, A. J., Bezila, K., Hoffman, S. G., Kindleberger, K., Manturuk, K., & Powers, A. S. (2009). "There must be a reason": Osama, Saddam, and inferred justification. *Sociological Inquiry*, *79*(2), 142-162.

Proctor, R.N. (2008). Agnotology: A missing term to describe the cultural production of ignorance (and its study). In *Agnotology: The Making and Unmaking of Ignorance , ed. R.N. Proctor and L. Schiebinger*, pp. 1–33. Stanford, California: Stanford University Press.

Qin, D., Plattner, G. K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., & Midgley, P. M. (2014). *Climate change 2013: The physical science basis*. T. Stocker (Ed.). Cambridge, UK, and New York: Cambridge University Press.

Qiu, X., Oliveira, D. F., Shirazi, A. S., Flammini, A., & Menczer, F. (2017). Limited individual attention and online virality of low-quality information. *Nature Human Behaviour*, *1*(7), 0132.

Rahmstorf, S. (2004). The climate sceptics. Potsdam Institute for Climate Impact Research, Potsdam, http://www.pik-potsdam.de/~stefan/Publications/Other/rahmstorf_climate_sceptics_2004.pdf

Rahmstorf, S., Foster, G., & Cahill, N. (2017). Global temperature evolution: recent trends and some pitfalls. *Environmental Research Letters*, *12*(5), 054001.

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

Readfearn, G. (2016). Revealed: Most Popular Climate Story on Social Media Told Half a Million People the Science Was a Hoax. *Desmogblog*. Retrieved from https://www.desmogblog.com/2016/11/29/revealed-most-popular-climate-story-social-media-told-half-million-people-science-was-hoax

Rich, P. R., & Zaragoza, M. S. (2016). The continued influence of implied and explicitly stated misinformation in news reports. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *42*(1), 62.

Roozenbeek, J., & van der Linden, S. (2018). The fake news game: actively inoculating against the risk of misinformation. *Journal of Risk Research*, 1-11.

Schauer, F., & Zeckhauser, R. (2009). Paltering. In B. Harrington (Ed.), Deception: *From ancient empires to Internet dating* (pp. 38–54). Stanford, CA: Stanford University Press.

Schmid-Petri, H., Adam, S., Schmucki, I., Haussler, T. (2015). A changing climate of skepticism: The factors shaping climate change coverage in the US press. *Public Understanding of Science*, 1-16.

Shao, C., Hui, P. M., Wang, L., Jiang, X., Flammini, A., Menczer, F., & Ciampaglia, G. L. (2018). Anatomy of an online misinformation network. *PloS one*, *13*(4), e0196087.

Shiraev, E. (2008). Character Assassination: An Interdisciplinary Approach. In *ISPP Annual Meeting, Paris*.

Smith, N., & Leiserowitz, A. (2012). The rise of global warming skepticism: exploring affective image associations in the United States over time. *Risk Analysis*, *32*(6), 1021-1032.

Supran, G. & Oreskes, N. (2017). Assessing ExxonMobil's climate change communications (1977–2014). *Environmental Research Letters*, *12*(8).

Swire, B., & Ecker, U. K. H. (2018). Misinformation and its correction: Cognitive mechanisms and recommendations for mass communication. In B. G. Southwell, E. A. Thorson, & L. Sheble (Eds.), *Misinformation and mass audiences*. Austin, TX: University of Texas Press.

Talisse, R., & Aikin, S. F. (2006). Two forms of the straw man. *Argumentation*, *20*(3), 345-352.

Tambuscio, M., Ruffo, G., Flammini, A., & Menczer, F. (2015, May). Fact-checking effect on viral hoaxes: A model of misinformation spread in social networks. In *Proceedings of the 24th International Conference on World Wide Web* (pp. 977-982). ACM.

Thorson, E. (2016). Belief echoes: The persistent effects of corrected misinformation. *Political Communication*, *33*(3), 460-480.

Tippett, C. D. (2010). Refutation text in science education: A review of two decades of research. *International Journal of Science and Mathematics Education*, *8*(6), 951-970.

Todd, C., & O'Brien, K. J. (2016). Teaching Anthropogenic Climate Change Through Interdisciplinary Collaboration: Helping Students Think Critically About Science and Ethics in Dialogue. *Journal of Geoscience Education*, *64*(1), 52-59.

Tranter, B. K., & Booth, K. I. (2015). Scepticism in a changing climate: a cross-national study. *Global Environmental Change: Human and Policy Dimensions*.

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

van der Linden, S., Leiserowitz, A. A., Feinberg, G. D., & Maibach, E. W. (2015). The scientific consensus on climate change as a gateway belief: Experimental evidence. *PLOS ONE*, *10*(2), e0118489.

van der Linden, S., Leiserowitz, A., Rosenthal, S., & Maibach, E. (2017). Inoculating the public against misinformation about climate change. *Global Challenges*, *1*(2).

van Duyn, E. & Collier, J. (2017). Priming and Fake News: The Effect of Elite Discourse on Evaluations of News Media. *APSA 2017 conference paper*.

Vraga, E. K., & Bode, L. (2017). Using Expert Sources to Correct Health Misinformation in Social Media. *Science Communication*, *39*(5), 621-645.

Weng, L., Flammini, A., Vespignani, A., & Menczer, F. (2012). Competition among memes in a world with limited attention. *Scientific Reports*, *2*, 335.

Wilson, K. M. (2000). Drought, debate, and uncertainty: measuring reporters' knowledge and ignorance about climate change. *Public Understanding of Science*, *9*(1), 1-13.

Yeaman, S., Schick, A., & Lehmann, L. (2012). Social network architecture and the maintenance of deleterious cultural traits. *Journal of The Royal Society Interface*, *9*(70), 848-858.

Zollo, F., Bessi, A., Del Vicario, M., Scala, A., Caldarelli, G., Shekhtman, L., Havlin, S. & Quattrociocchi, W. (2015). Debunking in a world of tribes. *arXiv preprint arXiv:1510.04267*.

ADDITIONAL READING

Bedford, D. (2010). Agnotology as a teaching tool: Learning climate science by studying misinformation. *Journal of Geography*, *109*(4), 159-165.

Cook, J. (2016). Countering Climate Science Denial and Communicating Scientific Consensus. *Oxford Encyclopedia of Climate Change Communication*. London: Oxford University Press.

Cook, J., & Lewandowsky, S. (2011). *The Debunking Handbook*. St. Lucia, Australia: University of Queensland. ISBN 978-0-646-56812-6. [available at http://sks.to/debunk].

Krugman, P (2018, December). Climate Denial Was the Crucible for Trumpism. New York Times. Available at https://www.nytimes.com/2018/12/03/opinion/climate-denial-trump-gop.html

Leiserowitz, A., Maibach, E., Roser-Renouf, C., Rosenthal, S., & Cutler, M. (2017). *Climate change in the American mind: May 2017*. Yale University and George Mason University. New Haven, CT: Yale Program on Climate Change Communication.

Lewandowsky, S., Ecker, U. K., & Cook, J. (2017). Beyond misinformation: Understanding and coping with the "post-truth" era. *Journal of Applied Research in Memory and Cognition*, *6*(4), 353-369.

van der Linden, S. (2018). Bad News. Available at https://www.getbadnews.com/

KEY TERMS AND DEFINITIONS

Agnotology: The study of culturally induced ignorance or doubt, particularly the publication of inaccurate or misleading scientific data.

Deductive Misinformation: Misleading arguments with definitive conclusions. Logically valid arguments with true premises and definitive conclusions are indefeasible (unfalsifiable)—no new claim can undermine the conclusion. An example of a deductive myth is "the sun is causing global warming."

Inductive Misinformation: Misleading arguments with provisionally true conclusions (e.g., probabilistic). Provisionally true claims can be falsified by new information. An example of an inductive myth is "there's too much uncertainty to know if humans are causing global warming."

Inoculation: A communication approach applying the metaphor of vaccination: by exposing people to a weakened (refuted) form of misinformation, they can be made resistant to subsequent exposure to persuasive misinformation.

Misconception-Based Learning: A teaching approach that directly addresses and refutes misconceptions as well as explain factual information, in contrast to standard lessons that teach the facts without explicitly addressing misconceptions. Also referred to as Refutational texts or agnotology-based learning.

Misinformation: Information that is initially presented as true but later found to be false. To be distinguished from disinformation, which refers to false information disseminated with deceptive intent. In contrast, the term misinformation is agnostic as to the motive of the source.

Paltering: Acting insincerely or misleadingly while still falling short of a full-bore lie. This can be achieved by fudging, twisting, shading, bending, stretching, slanting, exaggerating, distorting, whitewashing, and selective reporting.

Technocognition: The interdisciplinary approach of incorporating the findings from psychology, critical thinking, communication, computer science, and behavioural economics to inform the design of information architectures that encourage the dissemination of high-quality information and that discourage the spread of misinformation.