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

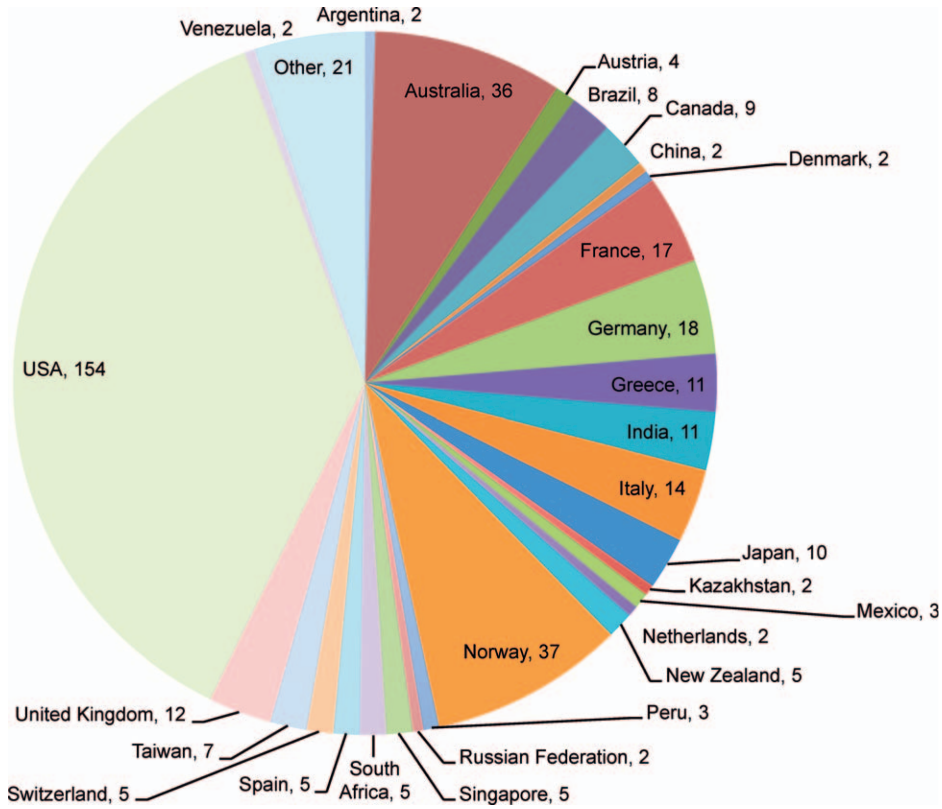

FIGURE 2: Number of media mentions of Cook et al. (2013), divided by country, from 16 May to 3 July 2013. Numbers provided by media-monitoring company Meltwater News, based on keywords selected to monitor online news specific to Cook et al. (2013). Numbers do not include print or broadcast media.

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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