Refutation Texts for Effective Climate Change Education

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ABSTRACT

Refutation texts, which are texts that rebut scientific misconceptions and explain the normative concept, can be effective devices for addressing misconceptions and affecting conceptual change. However, few, if any, refutation texts specifically related to climate change have been validated for effectiveness. In this project, we developed and tested three refutation texts related to climate change. The three texts, which are freely available for other educators and researchers to use, relate to (1) the enhanced greenhouse effect, (2) the distinction between climate and weather, and (3) the nature of ozone depletion and how it is not a major contributor to global warming. Participants in the study consisted of 146 undergraduates enrolled in various educational psychology courses. They were randomly divided into experimental and control groups. All participants completed a knowledge pretest, posttest, and delayed (2 wk) posttest. Experimental-group participants read one of the refutation texts, whereas control subjects read an unrelated text. Based on repeated-measures ANOVAs, results indicated that the refutation texts were generally effective in increasing knowledge and addressing the misconceptions that they were designed to address, although results were mixed for the weather versus climate text. Furthermore, there was little regression at the delayed posttest, except for the weather versus climate text (understanding that climate is usually measured over a 30-y period) and for global warming being unrelated to skin cancer. The importance of combining these texts with other instructional activities and simulations is discussed. © *2017 National Association of Geoscience Teachers*. [DOI: 10.5408/15-109.1]

Key words: refutation text, climate change, misconceptions, greenhouse effect

PROBLEM AND CONTEXT

Although misconceptions can develop in a number of content areas, they are especially prevalent in the sciences and can be extremely hard to overcome (Thijs, 1992; Shymansky et al., 1997). Learning about climate change is no exception. Despite the overwhelming consensus among climate scientists regarding the existence, causes, and effects of climate change, and the present public focus, it is still a controversial topic among much of the public, and misconceptions abound (McCaffrey and Buhr, 2008; Miller, 2012).

Research indicates that students may generalize major environmental issues and are often unsuccessful at distinguishing the problems from each other and separating the distinct mechanisms involved in each issue (Francis et al., 1993; Keller, 2006). For instance, students often confuse the natural greenhouse effect, global warming, and ozone depletion (Dunlop, 1998; Keller, 2006). Between reliance on their own experiences to make sense of scientific phenomena and their difficulty differentiating between weather and climate, it is not uncommon for students to use weather as "proof" for, or against, climate change (Vosniadou and Brewer, 1992; Sinatra et al., 2012). Students need some understanding of climate change–related subjects to overcome some misconceptions they may have acquired through the media, personal experience, and in other ways.

As indicated by Lombardi et al. (2013), the science of climate change is complex. People hold inaccurate conceptions about climate systems in general; for example, they hold misconceptions regarding the distinction between climate and weather, as well as regarding the causes, effects, and mitigation of climate change (Choi et al., 2010; Dutt and Gonzalez, 2012; Lombardi and Sinatra, 2012). Therefore, it may be necessary, in climate science, as in much of science education, to use instructional tools specially designed to counter misconceptions and encourage students to think about other perspectives or alternate conceptions (Vosniadou, 2008; Sinatra and Broughton, 2011).

One such instructional tool that may be particularly effective is refutation text. Traditional expository texts, which only explain concepts, are typically the texts used in science education, and students often have a hard time understanding them (McKeown et al., 1992). Consequently, they are often relatively ineffective at inducing students to change their conceptions (McKeown et al., 1992). Refutation texts, however, activate common misconceptions, explicitly refute them, and then state the correct or preferred conception; these texts can, therefore, be very effective for encouraging students to change their conceptions (Guzzetti et al., 1993; Hynd, 2001). An example of such a text is shown in Table I.

Three decades of research have overwhelmingly demonstrated that refutation texts are much more effective at eliminating misconceptions and changing learners' conceptions than traditional expository texts are (Guzzetti et al. 1993, Hynd and Alvermann, 1986; Diakidoy et al., 2003; Broughton and Sinatra, 2010; Tippett, 2010; Ariasi and Mason, 2011). Research also indicates that changes in conceptual understanding induced through refutation text are also more likely to be maintained over time (Hynd et al., 1994, 1997; Mason and Gava, 2007; Frede, 2008), and that refutation texts are generally preferred by learners (Guzzetti et al., 1997; Hynd, 2001; Mason et al., 2008). According to the coactivation hypothesis (Van den Broek and Kendeou, 2008), refutation texts work because they activate the

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TABLE I: Example of refutation text pertaining to ostriches.

Many people believe that an ostrich will bury its head in the sand when it is in danger. This is not true, however. If ostriches buried their heads, they would not be able to breathe! Ostrich chicks may hide from danger by lying with their necks stretched out along the ground. Adults may listen for sound with their heads near the ground, or they might run away.

Note. Text from Tippett, 2004.

misconception and correct the conception simultaneously; therefore, readers are more likely to become aware of the discrepancy between them. In addition, the refutation statement likely directs the learner's attention toward the new information to be learned, leading the learner to use cognitive strategies to resolve the conflict and to integrate the new, correct information into their understanding of a concept (Ariasi and Mason, 2011).

However, we are unaware of any refutation texts that have been published specifically on climate change, except for some by Cook et al. (2014), which we discuss in more detail below. Although there are Web sites and blogs that specifically refute myths about climate change (e.g., Gore, 2011; Skeptical Science, 2015; Real Climate, 2016), none of these sites were specifically designed for classroom use.

In regard to Cook et al. (2014), undergraduates wrote refutation texts as a class assignment in a course examining the nature and causes of climate-related misconceptions. The three best submissions, all with perfect scores, were subsequently published by Cook (2014) in Skeptical Science. The misconceptions addressed were (1) increased solar activity as an alternative cause of global warming, (2) the incidence of hurricanes is not increasing, and (3) many scientists in the 1970s predicted a coming ice age.

Our study builds on Cook's work in adding to the stock of publically available refutation texts and empirically validating their effectiveness. The misconceptions addressed by Cook (2014) were specifically tied to misinformation propagated by climate change skeptics, whereas our interest is in common confusions and misunderstandings that laypeople have, although these may be indirectly exploited by skeptics. McCaffrey and Buhr (2008) outlined 10 different widespread misconceptions that contribute to the public's lack of climate literacy. Our texts specifically address three of those misconceptions, namely, that (1) the greenhouse effect is entirely caused by humans, (2) climate change is primarily caused by a hole in the ozone, and (3) weather and climate are the same thing. For empirical documentation of the prevalence of these misconceptions, see Gautier et al (2006), Gowda et al. (1997), and Rebich and Gautier (2005).

One goal of our work was to evaluate the effectiveness of these texts empirically for college undergraduates not majoring in science.

METHOD
Participants

There were 146 undergraduate students from a large southwestern university who participated in one of three experiments to satisfy an introductory educational psychology or educational assessment research requirement. Participants ranged in age from 17 to 58 y (mean = 24.2, SD = 6.3). Most of the participants were female (75.9%), and most students were juniors (58.3%) with some sophomores (20.7%) and seniors (22.1%). Most of the participants were white (51.4%). Other ethnicities represented included Hispanic/Latino/Chicano (19.9%), Asian/Asian American (16.4%), African American (5.5%), biracial (5.5%), and other (1.4%). Most students had education majors (70.5%), and the average self-reported grade-point average was 3.15 (SD = 0.53). Table II shows the breakdown of those characteristics among the three experiments.

MATERIALS
Refutation Texts

The intervention for the three experiments in this study were three separate refutation texts created for climate change education for students ranging from ninth grade through college level, based on commonly held climate change–related misconceptions. (Our studies, however, focused specifically on undergraduate students.) The three texts related to (1) the enhanced greenhouse effect, e.g., the misconceptions that the greenhouse effect is only human caused and consists of a layer of pollution or dust that traps sunlight; (2) ozone depletion, e.g., misconceptions that the ozone hole is an actual hole and that it is causing global warming; and (3) weather versus climate, e.g., the misconceptions that short-term weather events are the same as climate change. Table III lists the specific misconceptions that each text addressed.

The three texts are available in the supplementary materials to this article (available in the online journal and at <http://dx.doi.org/10.5408/15-109s1>). The texts were written by the researchers to focus on targeted misconceptions identified by a team consisting of science educators, climate change experts, and educational psychologists. Input from the climate change experts, science educators, and educational psychologists involved in the project was incorporated to create pedagogically sound, scientifically accurate texts to educate people regarding these topics. The weather versus climate text was prepared and reviewed by a secondary geoscience teacher. The texts on the greenhouse effect and ozone depletion were reviewed for content validity by a science specialist with expertise in climate change as well as pedagogy and by an educational psychologist with expertise in creating and evaluating refutation texts. Multiple rounds of revisions were made based on the experts' suggestions. The texts were then piloted with three to four undergraduates individually, who read each sentence and voiced their understanding; this process resulted in several minor wording changes to eliminate ambiguities.

The texts specifically "coactivate" both the misconception and the more-normative conception (Kendeou et al., 2011) by describing the misconception ("Some people believe"), refuting it ("However, this is not correct") and by explaining the more normative conception. Following is a brief example from the enhanced greenhouse effect text.

TABLE II: Sample size and demographic information by refutation text experiment.

Variable	Text			Overall
	Enhanced Greenhouse Effect	Weather Versus Climate	Ozone Depletion	
Participants, No.	44	68	34	145
Age				
Mean	26.3	23.07	23.59	24.15
SD	10.7	4.38	4.62	6.34
Gender				
% Female	88.6	76.1	58.8	75.9
% Male	11.4	23.9	41.2	24.1
Grade				
% Freshmen	4.7	2.9	2.9	3.4
% Sophomores	20.9	20.6	20.6	20.7
% Juniors	51.2	57.4	50.0	53.8
% Seniors	23.3	19.1	26.5	22.1
Ethnicity				
% White	56.8	48.5	50.0	51.4
% Hispanic/Latino	29.5	14.7	17.6	19.9
% Asian/Asian American	9.1	20.6	17.6	16.4
% African American	2.3	4.0	8.8	5.5
% Biracial	2.3	7.4	5.9	5.5
% Other	0.0	2.9	0.0	1.4
% Education majors	72.7	73.5	61.8	70.5
Grade-point average				
Mean	3.10	3.16	3.18	3.15
SD	0.65	0.54	0.36	0.53

People often confuse the greenhouse effect with global warming. Many people believe that the greenhouse effect is dangerous and created through human activity. You may have thought this too. However, this is incorrect. The Earth's greenhouse effect is NOT dangerous. It is NOT caused by humans. The Earth's greenhouse effect occurs naturally. It helps keep the planet's average temperature comfortable for humans to live on the Earth. Without a greenhouse effect, Earth's average temperature would be about −1°F. This is about 60°F colder than the normal average temperature. Life on Earth might not exist at all without the greenhouse effect.

TABLE III: Misconceptions addressed by the refutation texts.

Text	Misconceptions
Enhanced greenhouse effect	1. The greenhouse effect is unnatural and dangerous.
	2. Greenhouse gases are a layer of pollution or dust that trap CO_2 inside (like a greenhouse).
	3. Ozone depletion causes global warming.
	4. There is nothing we can do about global warming.
Weather versus climate	5. Climate changes from year to year.
	6. A few extremely cold days in the winter is evidence against climate change.
	7. Wind and sunlight control the climate much more than ocean currents.
Ozone depletion	8. Ozone depletion causes global warming.
	9. Global warming causes ozone depletion.
	10. The ozone hole is an actual hole in the Earth's atmosphere.
	11. Increased levels of ultraviolet radiation coming into the Earth's atmosphere from ozone depletion heat up the Earth's climate.
	12. Global warming is causing increased levels of skin cancer.

The text then goes on to differentiate the natural and enhanced greenhouse effects.

In writing the texts, we had to make some difficult decisions as to what to include, given that the texts were being written for general education students. For example, the text on the ozone hole does not mention that chlorofluorocarbons and hydrochlorofluorocarbons are greenhouse gases. The decision not to discuss these was an intentional one made on pedagogical grounds to avoid making the text overly complex and to help separate the association of the ozone hole from causes with greater impacts on the enhanced greenhouse effect.

In addition, we chose to use the classical definition of *climate* specified by the World Meteorological Organization (2016) as an average over at least 30 y, rather than simply "over a long period of time." Although we recognize that some researchers use a different time frame relative to their purposes, e.g., measuring climate over thousands of years in studying past ice ages, or only over 20 y for some variables in the Intergovernmental Panel on Climate Change (IPCC) reports (Baede, 2015), for our purposes, it was important to define *climate* as unambiguously as possible. The classical definition is a widely used one (e.g., see U.S. Global Change Research Program—Climate Change Science Program, 2009). Each of the three texts was assessed for readability. The texts were found to have a Flesch-Kincaid grade level ranging from 8.2 to 9.0 and Flesch reading ease scores ranging from 54.0 to 58.9, indicating that each text was relatively easy to read. A pilot study was also conducted to examine the comprehensibility of each text; revisions to each text were then made based on the results of the pilot. The texts ranged in length from 1,009 to 1,016 words and addressed three to five common misconceptions each.

Knowledge Measures

Knowledge measures, consisting of multiple-choice, true/false, and open-ended constructed-response questions, were created for each text based on the misconceptions addressed and the scientific information contained in the texts. Each assessment was reviewed for content validity by a science educator with expertise in climate change. Overall, each assessment contained from three to five constructed-response questions, 4–13 multiple-choice questions, and zero to six true/false questions. The assessments and scoring rubrics are included in the supplementary materials (available in the online journal and at <http://dx.doi.org/10.5408/15-109s2>).

In aggregating the data, we generated a score for the selected-response questions, based on the number of correct answers, and a separate score for the constructed-response questions. For the selected-response scores, reliabilities (α) were 0.80, 0.68, and 0.88 for the enhanced greenhouse, weather versus climate, and ozone-depletion texts, respectively. Based on a review of the questions for possible ambiguities, three questions were deleted from the analysis of the weather versus climate text: Question 4 of the multiple-choice questions and Questions 1 and 3 of the true/false items.

For the constructed-response questions, scoring rubrics were developed for each question and then refined during coding to capture student ideas not contained in the initial rubrics, with previously scored responses then rescored. In this way, a student could receive credit if they mentioned a legitimate line of reasoning that was not in the text.

Each constructed-response question was scored by two raters working independently; the raters did not know which condition or time (e.g., pretest or posttest) was associated with each answer. The raters periodically met to discuss and resolve discrepancies. Interrater reliability ranged from 0.76 to 0.99 (mean = 0.89), except for the mechanism component of Question 1 of the greenhouse-effect text, for which the reliability was 0.56 or 0.80 within one-quarter point. These figures were based on samples of 22%–66% of all responses, depending on the question and how quickly the two raters could achieve adequate agreement. All the responses were then rescored. Because the range on each rubric varied (e.g., 0–3, 0–4), some scores were multiplied by an adjustment factor, so ranges would be equivalent, e.g., scores on a 0–3 rubric would be multiplied by 1.33, so the range would be 0–4. The scores on all constructed-response questions for a particular text were then summed to compute a single composite score for the constructed-response questions. These were not combined with the scores for the selected-response questions because the two different types of scores were scaled differently and reflected somewhat different competencies, specifically, written production and deeper conceptual understanding versus knowledge recognition.

Procedures

Each student participated in two survey sessions, either in person or online for the weather versus climate text. During the first session, each student completed a form in which they gave their informed consent to take part in the research. Participants were then randomly assigned to either the experimental group or the control group. Students then completed a demographics survey and a knowledge assessment. Next, participants in the experimental group were asked to read a refutation text presenting the scientific conception of the phenomenon, whereas participants in the control group were asked to read a traditional expository text presenting the scientific conception of an unrelated phenomenon. Participants then completed the knowledge-assessment survey again. At the second session, which took place 2 wk after the first session, students again completed the knowledge-assessment survey. The reason for the second session was to conduct a delayed posttest of enduring conceptual change.

RESULTS

Table IV shows the overall means and standard deviations of the knowledge measures for the pretest, posttest, and delayed posttest. A mixed model 2 $\times$ 3 repeated-measures ANOVA was then performed to examine the effectiveness of each refutation text compared with the control text. The results are shown in Table V. The time-by-treatment interactions show whether there was statistically more growth in one group than there was in the other. The F-values are used to compute statistical significance; a large value indicates that there was a large amount of variation among the means when compared with the within-group variation.

Plots of the means are shown in Fig. 1 for the selected-response questions and Fig. 2 for the constructed-response questions. Because students can forget knowledge over time,

TABLE IV: Means (and SD) of scores for each test by question type[1]

	Greenhouse Effect			Weather Versus Climate			Ozone Depletion		
	No.	Mean	SD	No.	Mean	SD	No.	Mean	SD
Selected response									
Pretest	40	4.68	(2.32)	68	5.74	(1.71)	31	5.65	(1.74)
Posttest	40	7.03	(2.97)	68	6.19	(1.99)	31	6.94	(2.71)
Delayed posttest[2]	40	7.10	(2.49)	54	6.46	(1.78)	31	6.45	(3.05)
Constructed response									
Pretest	44	2.68	(1.47)	66	3.33	(2.26)	33	1.29	(1.80)
Posttest	44	4.13	(2.06)	68	5.44	(3.47)	33	2.62	(2.28)
Delayed posttest[2]	40	3.88	(1.84)	53	5.19	(3.51)	32	2.88	(2.23)

[1]Scores are for the entire sample. Selected response includes multiple-choice and true/false questions; scores were computed out of 13 possible points for the greenhouse text, seven for the weather versus climate, and 10 for ozone depletion. Constructed-response questions were open-ended; values shown are averages of the means for three questions for the greenhouse text, five for weather versus climate, and three for ozone depletion. The scores on each constructed-response question were placed on a standard three-point scale (four points for the greenhouse text), and then, the totals computed.
[2]Reflects a 2-wk delay.

the statistical models were quadratic, allowing the delayed posttest means to be lower than the first posttest means, as shown in Figs. 1 and 2.

For the enhanced greenhouse effect and ozone depletion texts, there was significantly more knowledge gained by the experimental group than there was by the control group. There were significant effects for the weather versus climate text only for the constructed-response questions; the selected-response analysis showed only marginal change in the means ($p = 0.13$). Using the Cohen (1988) guidelines for partial η^2 ($0.06 \geq$ medium effect; $0.13 \geq$ large effect), all the statistically significant effect sizes were large or very large. Except as noted above, the differences between the experimental and control groups were all statistically significant at the posttest and delayed posttest time points, as indicated by the nonoverlapping error bands in the Figs. 1 and 2.

For the enhanced greenhouse effect and ozone depletion texts, inspection of the posttest and delayed posttest means for the experimental group indicated only a slight loss in knowledge by the time of the delayed posttest, specifically no more than 13.4%. A notable decline was seen only for the weather versus climate text, specifically, of 21.3% on the constructed-response questions.

To better understand these effects, we examined which questions in the experimental group showed the strongest gains. Our intent was to determine what students were "really learning" from these texts and whether misconceptions were being addressed. The questions with the greatest learning gains are shown in Table VI.

The data in the Table VI indicate that there were three misconceptions successfully addressed by the refutation text: (1) that an ozone hole is a primary contributor to global warming, (2) that climate is the same as weather, and (3) that the greenhouse effect is entirely human caused. There were also strong learning gains on some factual questions that were not necessarily tied to misconceptions, e.g., that the Earth gives off infrared radiation. Although not shown in Table VI because the data were summarized by means rather than by percentage of correct responses, students also learned that large bodies of water can affect climate. Specifically the mean on the constructed-response Question 5 for the weather versus climate text increased from a score of 0.60 at pretest to 0.91 at posttest and to 0.82 on the delayed posttest. Although not shown in Table VI, on Question 3, which related to the warming of the oceans as evidence of climate change, there was not, initially, a significant effect, but further analysis showed that this was because we gave credit for other legitimate pieces of evidence for climate change, such as melting glaciers. When we scored the responses just for mentioning the warming of the oceans, there was a 30.2 percentage point increase from the pretest to the posttest, indicating that many students were at least processing the information in the text. These gains were preserved on the delayed posttest.

TABLE V: Times-by-treatment interactions.

Text	Question Type[1]	F	df	η_p^2
Enhanced greenhouse effect	SR	23.61***	1, 43	.38
	CR	10.42**	1, 38	.22
Weather versus climate	SR	0.13	1, 51	.05
	CR	9.09**	1, 50	.15
Ozone depletion	SR	15.37***	1, 29	.35
	CR	7.86**	1, 29	.21

[1]Values based on a nonlinear contrast. SR = selected response; CR = constructed response.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

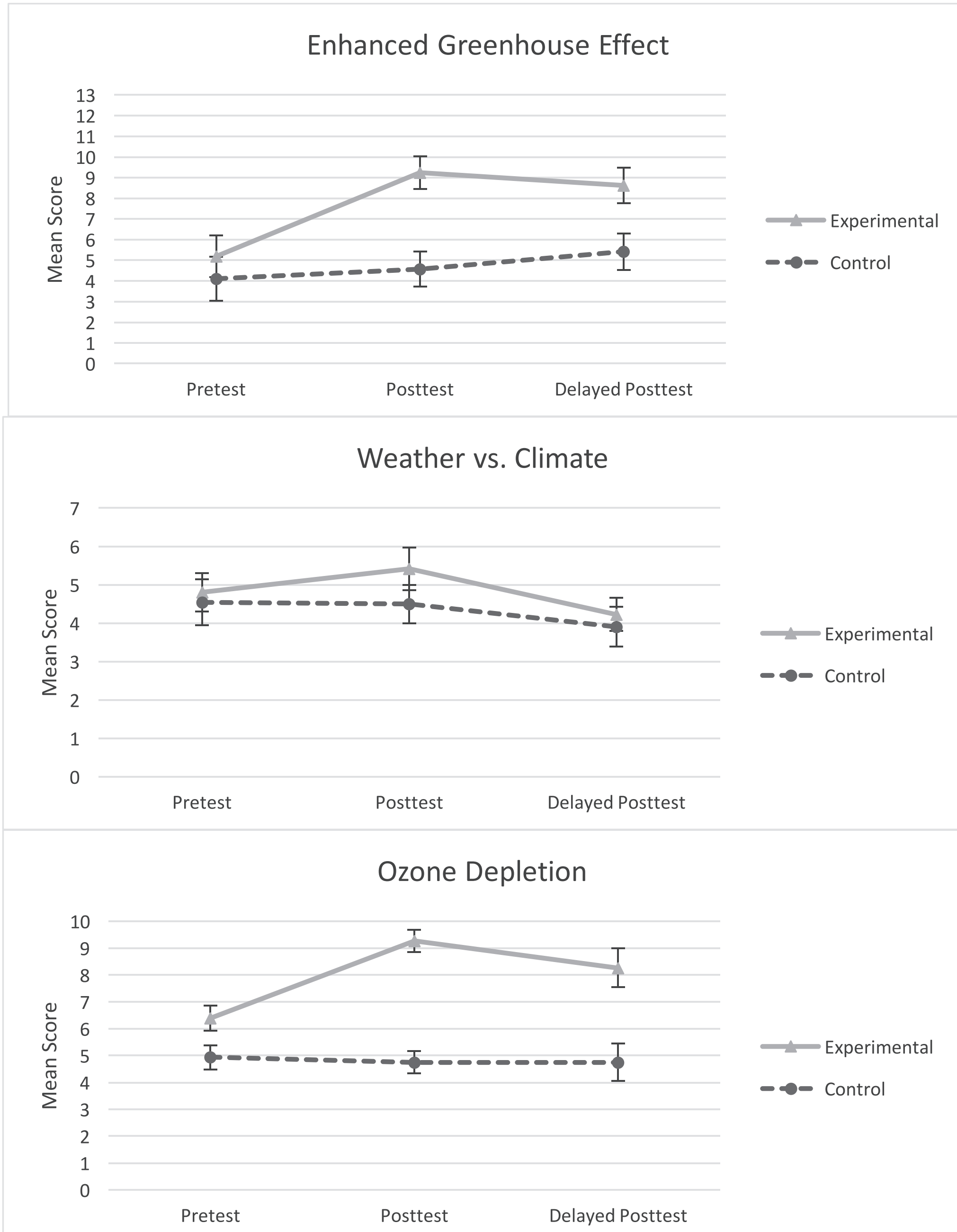

FIGURE 1: Mean score over time for selected-response questions, by text. Error bars reflect a 95% CI. The posttest was administered the same day as the pretest; the delayed posttest was administered 2 wk later.

For the weather versus climate text, what was driving the decline in the delayed posttest averages for the aggregate scores on the constructed-response questions? The means for the individual questions are shown in Fig. 3. The decline was largely driven by Question 4, "What time period is considered to determine climate change?" and to a lesser degree, Question 1, "What is climate?" A high score on Question 1 required mentioning the 30-year criterion; fewer students did so in the delayed posttest. Some students may have forgotten the exact number after a delay of 2 wk; only about one-half of the students who showed gains on the constructed-response question retained that knowledge by the time of the delayed posttest.

DISCUSSION

Educational research has shown that students, as well as lay adults, harbor various misconceptions about natural phenomena (Dole and Sinatra, 1998; Chi, 2008). These misconceptions may arise from mental shortcuts and heuristics that cause people to jump to conclusions, e.g., that a few very cold days are evidence against global warming (McCaffrey and Buhr, 2008). The news media, which is a primary source of many people's information about climate, may also contribute to these misconceptions because the media often oversimplifies complex information (Gowda et al., 1997). Many of these misconceptions are difficult to counter with traditional means of instruction

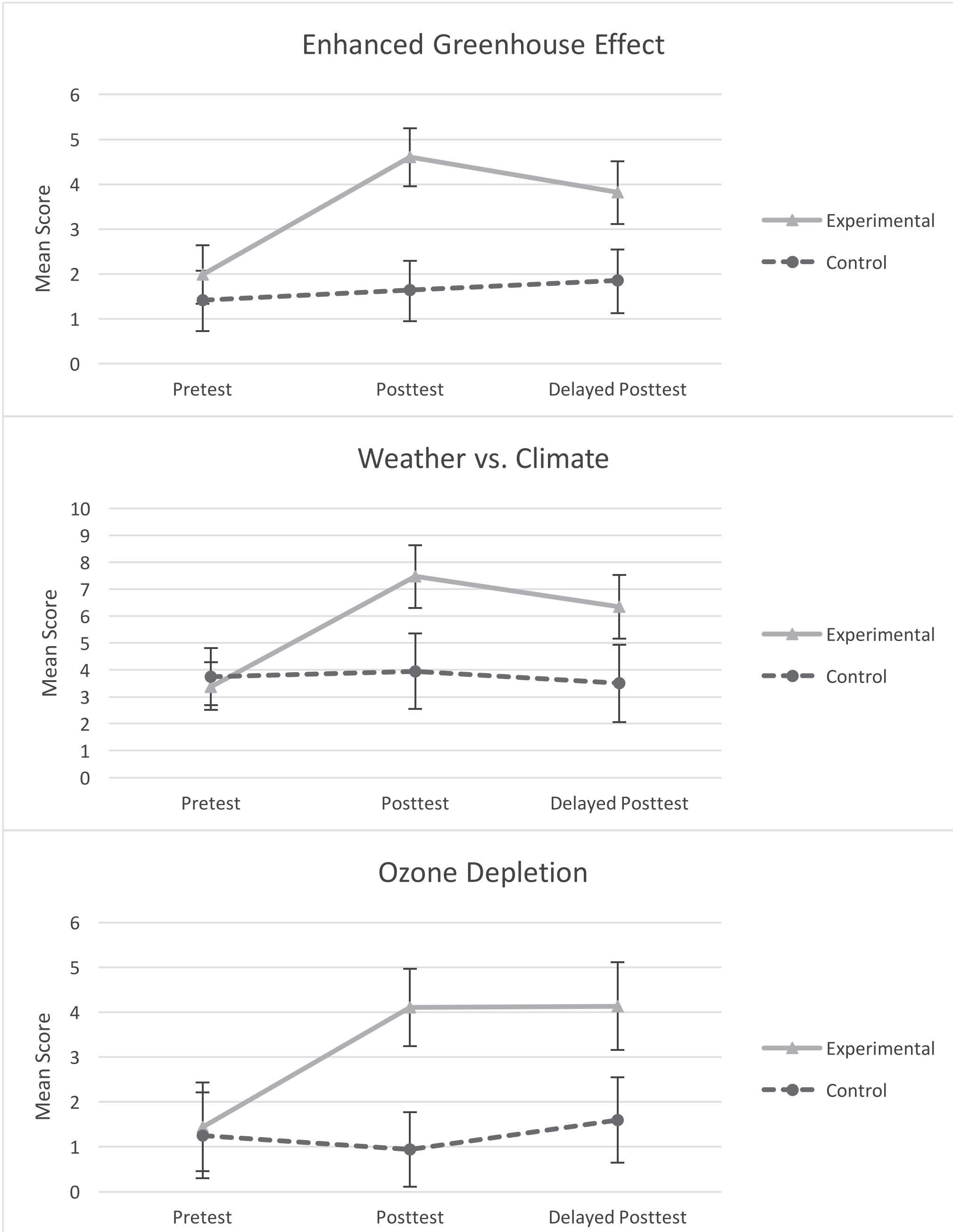

FIGURE 2: Mean score over time for constructed-response questions, by text. Error bars reflect a 95% CI. The posttest was administered the same day as the pretest; the delayed posttest was administered 2 wk later.

(McCaffrey and Buhr, 2008). Therefore, it is important for geoscience educators to be aware of techniques, particularly the use of refutation texts, that have been proven effective in countering such misconceptions.

This article presents our first steps in developing and evaluating refutation texts for climate change education. We found that our texts were effective in remedying the misconceptions they were targeting. There was clear evidence that students learned that ozone depletion is not the cause of global warming and that there is not an actual hole in the Earth's atmosphere, and also, that there is a difference between the natural and enhanced greenhouse effects. There was also some evidence that students learned that climate and weather are different concepts, with climate measured over a much longer time, and that the warming of the oceans contributes to climate change. Knowledge gains were generally preserved after a 2-wk delay, with the degree of regression in overall scores ranging from zero to only 13.4%. The regression on individual questions was seldom more than 25%, with two exceptions we discuss later.

Refutation texts can be powerful because they speak directly to misconceptions that students may harbor, putting the students into a state of cognitive disequilibrium (Piaget, 1952). That disequilibrium is then resolved by presenting the alternative, normative conception. According to the coactivation hypothesis, coactivation attracts readers' attention to

TABLE VI: Assessment questions with greatest learning gains.

Question	Concept	% Correct		
		Pretest	Posttest	Delayed Posttest
Enhanced greenhouse effect text				
4	The greenhouse effect is natural.	40.9	100.0	100.0
5	Greenhouse effect makes Earth fit for human habitation.	27.3	86.0	86.0
9	Correct identification of greenhouse gases.	18.2	59.1	54.5
7	Earth's surface gives off infrared radiation	36.4	81.8	59.1
8	Solar energy equilibrium.	18.2	59.1	50.0
15	Greenhouse effect unrelated to ozone depletion.	27.3	50.0	59.1
16	Ozone depletion unrelated to greenhouse effect.	22.7	54.5	45.5
Weather versus climate text				
3	Nature of prevailing winds.	18.2	54.6	48.4
1 CR[1]	Climate measured over 30 y.	21.2	46.8	32.3
4 CR[1]	Climate measured over 30 y.	4.4	27.9	16.2
Ozone depletion text				
7	No actual hole in atmosphere.	35.3	94.1	93.3
8	Global warming not cause skin cancer.	52.9	94.1	73.3
4	Ozone depletion not causing global warming.	52.9	100.0	93.3
5	Global warming not causing ozone depletion.	52.9	94.1	86.7

[1]Constructed-response questions: "What is climate?" and "What time period is considered to determine climate change?" Data reflect the percentage of students with scores of three, reflecting knowledge of 30-y criterion.

the discrepancy and allows readers to connect the two conceptions and, in some sense, "overwrite" the incorrect conception with the correct one. Furthermore, the correct conception is explained in simple terms, making it more understandable and plausible (Lombardi et al., 2013).

Cook and Lewandowsky (2011) have argued that refutation messages should not start by stating "the myth" (especially in a headline) but should instead state and explain the core facts. The myth should then be stated only briefly before explaining how the myth is misleading. The rationale is to avoid a backfire effect in which the myth becomes more familiar to the reader and, in turn, more accepted. That argument was partially supported in a study by Skurnik et al. (2005) in which warning about false claims regarding flu vaccines and other medical topics led to greater acceptance of the myths, especially in older adults. However, that was not a refutation text study; the independent variable was the number of times the participants were told a claim was false, not the order of presentation of claims labeled true or false. Thus, the Cook and Lewandowsky (2011) recommendation is in need of additional empirical verification. Furthermore, our results are not consistent with Cook and Lewandowsky's (2011) recommendation because our results indicate that a refutation text can be effective by first stating and explaining the misconception, at least among college students (see also Braasch et al., 2013). One salient difference is that the Cook and Lewandowsky (2011) recommendation was made in the context of designing media messages in which the myth was stated in an attention-grabbing headline, whereas our texts were written in a more expository style.

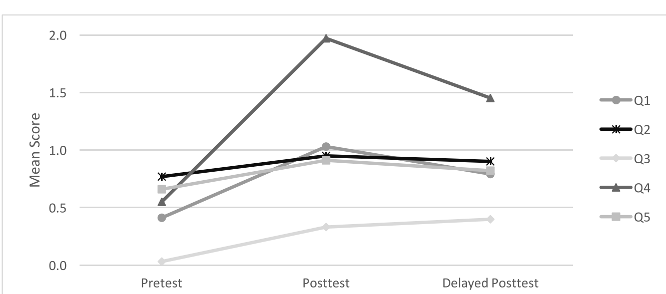

FIGURE 3: Weather versus climate text, with mean scores over time for individual constructed-response questions. (Q1: What is climate? Q2: What is weather? Q3: What evidence indicates climate change is taking place? Q4: What time period is considered to determine climate change? Q5: What impact do large bodies of water have in determining climate change?)

Limitation and Suggestions for Future Research

There were, however, some limitations to our study, which we discuss below, followed by a discussion of the implications for practice.

Limits to Effectiveness

Although our texts were effective in addressing most misconceptions, as mentioned above, there were two concepts in which there was significant regression in the time between the posttest and the delayed posttest. The first concept was that global warming is not linked to skin cancer; the mean score declined about 50%.

The second concept was knowledge of the 30-y criterion for measuring climate; only about one-half of the students who showed gains on the constructed-response question retained that knowledge by the delayed posttest. It is unclear whether the exact figure ("30 y") was less salient after the delay and, therefore, mentioned less in the constructed-response questions, or the conflation of weather and climate was such a strong misconception that it interfered with retrieving more newly acquired conceptions. The data suggest the former because in only three cases in the experimental group did the students regress on Question 1 to a zero score, reflecting complete confusion between weather and climate. In 11 cases showing regression, responses on the delayed posttest still reflected that climate was measured over an "extended period" or over "several years." This result may, therefore, not be highly problematic because, as noted in the Method section, not all researchers accept the classical 30-y criterion anyway, but what is important is that climate not be confused with short-term weather patterns and events, such as an unusually cold day or season.

The weather versus climate text was only partially effective. There were significant effects on the constructed-response mean scores but not on those for the selected-response questions. Whereas most students did learn the main gist of the text, i.e., how weather differs from climate, some of the details of the factors influencing both weather and climate were learned less well. We rewrote the text to make it potentially more effective and to eliminate some minor content inaccuracies. The revised text is contained in the supplementary materials along with the initial text (available in the online journal and at <http://dx.doi.org/10.5408/15-109s1>).

One other limitation, specifically regarding the enhanced greenhouse text, is that there was no evidence that students acquired a robust understanding of the greenhouse effect. That topic was not one in which students displayed strong learning gains. The text most likely needs to be supplemented with strong visual models and demonstrations to illustrate a mechanism as complex as the greenhouse effect (see, e.g., Nussbaum et al., 2015). Future research should address the effect of adding images to the text. Likewise, the number of correct responses regarding the question pertaining to what can be done to mitigate climate change showed some increase at posttest, specifically from 77% correct at the pretest to 95% at posttest, but the percentage of correct responses returned almost to baseline by the time of the delayed posttest (81%). The text only briefly mentioned some of the mitigation options, and many students did not remember all of them after the 2-wk delay. Supplemental instruction would, therefore, also be needed on that topic.

Methodological Limitations

We note several other limitations in our study. First, even though many students provided the normative answers on our assessments, learning is not the same as acceptance, and we cannot know for sure whether these students truly accepted the science of climate change. This is a topic that could be addressed in future research. Second, the participants in our study were not actually enrolled in an introductory geoscience course. On the other hand, the participants in our sample were somewhat similar to many nonmajors taking these courses, although our sample likely consisted of proportionately more females. Future work should address the impact, if any, of such gender differences. Third, the texts presented in this article require additional refinement and testing on various other populations, such as high-school students. In addition, we encourage other researchers to develop refutation texts on other climate misconceptions, such as the seven other misconceptions outlined in McCaffrey and Buhr (2008; Table I).

Regarding the texts examined in this study, although we found our texts to be effective, the comparison was made with an unrelated, expository text and not with a parallel text without the refutation component. We had the control participants read a text so that the time between the pretest and posttest would be equivalent, as would the overall time and effort expended by each participant. We used an unrelated text so that the overall effectiveness of the texts could be assessed. Our goal was not to compare refutation and expository text formats because there is substantial evidence that the former is superior (Tippett, 2010). Nonetheless, future research could use a more topically related control text to verify the power of the refutational components.

Finally, although we drew on the expertise of several content experts in preparing the text, the weather versus climate text was not sufficiently reviewed. Reviewers of earlier versions of this manuscript suggested some changes be made to that text, as did our climate-change specialist. Therefore, a revised weather versus climate text is presented in the supplementary materials, along with the initial text (available in the online journal and at <http://dx.doi.org/10.5408/15-109s1>). The revised text should be used in future instructional and evaluation efforts so that it can be further validated and refined.

Implications for Practice

Although additional research is required to determine how best to use and integrate these texts into a geoscience curriculum, we can tentatively offer some suggestions based on prior research (Tippett, 2010).

Recommendations for Use

First, research suggests that it is helpful to activate students' prior knowledge before they read a refutation text, through either asking adjunct questions or performing a demonstration. Guzzetti (1990) found that reading the text before conducting a demonstration designed to elicit the same concepts was less effective than performing the demonstration first. On the other hand, activating prior knowledge can also reinforce misconceptions when that knowledge is inaccurate, so it is helpful to include a warning that some of that information may be faulty (Tippett, 2010; Ecker et al., 2011).

Second, "refutation text may be more effective when misconceptions are single ideas rather than complex concepts, as less change is required to accommodate new information (Chi, 2008)" (Tippett, 2010, p. 965). For more complex concepts, refutation text should be supplemented with other activities, such as videos, hands-on experiments, collaborative argumentation over alternative models (Lombardi et al., 2013), and graphic organizers that evaluate alternative models (Chinn and Buckland, 2012).

We would also add that refutation texts can be easily incorporated into professional development (PD) sessions. According to McCaffrey and Buhr (2008) and Plutzer et al. (2016), many teachers, especially at the middle and high-school levels, possess gaps in their content knowledge and harbor misconceptions. These teachers also need instructional tools that address learning gaps and misconceptions in their students. Teacher training that uses refutation texts similar to those that we developed can serve both purposes: addressing potential deficiencies in teachers' content knowledge and, simultaneously, teaching about conceptual change pedagogy (which of course could also address other conceptual change techniques).

Integrating into a Geoscience Curriculum

Part of the attraction of using a refutation text is that research suggests that these texts can often be effective if just read by students, without any additional activities or the use of best practices (Tippett, 2010). For example, Diakidoy et al. (2003) found that, even with students who are not used to reading about a complicated topic via text, combining a refutation text with their standard instruction (teacher presentation, demonstration, and questioning) led to better performance than did standard instruction alone or standard instruction plus a traditional expository text. A simple way to use the texts would be to assign them to be read as homework along with appropriate chapters of the textbook and then, as part of a lecture–discussion, to question students in class about the concepts, so as to assess whether the texts were read and understood. In addition, some instructors assign excerpts from scientific reports, such as the "Frequently Asked Questions" sections in the IPCC (2007) report. There are Frequently Asked Question (FAQ) passages, for instance, on "What factors determine the Earth's climate?" "What is the relationship between climate change and weather?" and "What is the greenhouse effect?" These FAQ passages, however, are generally not written in a refutational style. Instructors could ask students to read a refutation text before reading these excerpts to enhance the latter's effectiveness.

In addition, Tippett (2010) recommends that teachers "locate and use trade books that use refutation texts." Most texts use only an expository format, despite the research during the past 20–30 y documenting the effectiveness of a refutation format. Therefore, it is a boon when teachers can locate instructional materials with a refutation format. When that is not possible, or when the materials do not target all the misconceptions that teachers desire, supplementing the materials with the type of texts contained in this article is an option.

Of course, the refutation texts could likely also be used in conjunction with argumentation and classroom discussion to further enhance conceptual change. This may be important given the politicized nature of the discourse on climate change (Jacques and Dunlap, 2008) and the existence of confirmation bias leading to processing of evidence supportive of preexisting conceptions (Taber and Lodge, 2006). In classrooms in which this appears to be a problem, collaborative argumentation, in which students can flexibly change sides or find middle ground (Rebich and Gautier, 2005; Nussbaum, 2008), in conjunction with graphic organizers that prompt more-balanced evaluation of opposing sides (Nussbaum et al., 2007), have been shown to facilitate conceptual change. It would be hoped that some students would refer back to the refutation texts in critiquing the arguments and evidence made by other students or other parties, such as politicians.

Refutation texts could also be used with the type of "agnotology-based" curricula advocated by Cook et al. (2014). According to Bedford (2010), much of the disconnect between the views of ordinary citizens and scientists is due to an organized campaign of disinformation that creates doubt and confusion in the public's mind (Jacques and Dunlap, 2008), a process that Proctor (2008) calls *agnogenesis*. The term *agnotology* refers to the scientific study of agnogenesis. Bedford (2010) describes how agnotology can be incorporated into the geoscience classroom, e.g., by having students read and critique works such as the novel, *State of Fear* (Crichton, 2004). Refutation texts could be incorporated into an agnotology curriculum early on, when students are first learning about the content, and then certain misconceptions discussed later on when agnogenesis is examined. For example, students could discuss how media messages, deliberately or otherwise, confuse the distinction between weather and climate. Such "active learning" would help to elaborate and deepen students' understanding (Nussbaum, 2008).

In closing, it is important for geoscience educators to be aware of the power of refutation text in addressing scientific misconceptions in general, but especially those related to climate change, given that the topic is replete with misconceptions and agnogenesis. Once the texts are developed, they can be quickly read by students and are thus a time-efficient instructional tool. Educating students about climate change is extremely important, and geoscience educators need to use a variety of tools, including refutation texts, to help overcome various misconceptions about the topic.

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