The Problem of Teaching the Science of Climate Change:
A Call for Critical Thinking.

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Abstract

In this treatise, I hope to show that science educators can engage students philosophically with a distinctive methodology that incorporates critical thinking applied to the pressing issue of climate change—as it has played out in the public sphere. Specifically, this approach can be applied to claims about climate change to help the science educator present a more robust picture about this life-threatening issue and deal directly and systematically with students' misconceptions and resistance to modern climate science.

I. Introduction

The problem of teaching the science of climate change begins with the stark fissure between scientists and citizens about whether climate change exists and/or is due primarily to the human use of fossil fuels. Moreover, there is the problem of public resistance to thinking critically[1] about this issue—usually fueled by hardened beliefs, motivated reasoning, fallacious thinking, and misinformation.[2] Accordingly, there is a need to deal with publicly popular resistance to, and misconceptions/distortions about, the issue of climate change.[3] This demands that we promote and defend the integrity of science education in the face of the climate change controversy; and, help teachers gain the confidence and support they need to teach the science of climate change effectively against the tide of cultural, political, and/or religious ideological interference.[4]

This is crucial for our survival as a species because society and the relationships among individuals within a society influence how we make choices and how policy

[1]Throughout this treatise, we will operate under a common core understanding of **critical thinking** that is about taking some **argument** apart using **analysis** and **evaluating** whether some derived conclusion follows from the evidence. See 1. An Introduction to Critical Thinking (https://www.youtube.com/watch?v=oefmPtsV_w4&feature=related); and, 2. What is Critical Thinking? (https://www.youtube.com/watch?v=6OLPL5p0fMg). Accessed August 18, 2019.

[2]For a description and survey of the stark fissures between scientists and citizens on a range of science, engineering and technology issues see Funk, C., and L. Rainie. 2015. Public and scientists' views on science and society. *Pew Research Center* (http://www.pewinternet.org/2015/01/29/public-and-scientists-views-on-science-and-society/). Accessed September 5, 2019.

[3]Union of Concerned Scientists. 2018. Scientists agree: Global warming is happening and humans are the primary cause (https://www.ucsusa.org/global-warming/science-and-impacts/science/scientists-agree-global-warming-happening-humans-primary-cause#.WwekqK6nGUk). Accessed September 2, 2019.

[4]Worthy of attention or notice here is the *National Center for Science Education* (https://ncse.com/). Accessed August 18, 2019. The NCSE defends the integrity of science education against ideological interference. This organization works with teachers, parents, scientists, and concerned citizens at the local, state, and national levels to ensure that topics like climate change are taught accurately, honestly, and confidently.

discussions might (or might not) improve how we think about climate change. Accordingly,

> *Only when the currently low scientific literacy of the American population rises to the level of accurate and sympathetic understanding of science will the appeal of nonscience, pseudoscience, and just plain bad science diminish sufficiently to disable the quackeries that today prey upon people. But let it be noted: at least in America and probably in the United Kingdom as well, no improvement is to be expected until there are major changes in the way schoolteachers are trained to teach science.*[5]

Without a doubt, a critical concern having serious social policy implications is the distrust or denial of the **science of climate change**.[6] Some people are undecided about, or simply avoid facing the consequences of, climate change; but, others deny climate change exists altogether or that it is due primarily to the human use of fossil fuels. This problem of public resistance to climate change is compounded with the reality that science faculty have often avoided teaching controversial issues in science classes, since much of the students' resistance is framed in cultural, political, and/or religious terms and science teachers are usually reluctant to address such ideas in class.[7]

Moreover, many science instructors are simply not able to master and teach critical thinking well[8] and/or are not entirely effective in passing on scientific knowledge because they are themselves suffering from cognitive dissonance.[9] As noted by Eve and Dunn (emphasis mine),

> *[a] review of recent reports on the state of education in the U.S. indicates that there is much concern today over whether science teachers have received adequate instruction in the **philosophy and methodology of science**. Because this type of training is a critical tool for distinguishing between bogus scientific beliefs and*

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[5]Forrest, B., and P. R. Gross. 2005. The wedge of intelligent design: Retrograde science, schooling, and society. *Scientific values and civic virtues*, ed. N. Koertge. New York: Oxford Univ. Press, 205-206.

[6]The science behind climate change may be gleaned from **APPENDIX A: Web Video Resources for the Science Class.**

[7]Nelson, Teaching evolution (and all of biology) more effectively: Strategies for engagement, critical reasoning, and confronting misconceptions, 213-225.

[8]Unfortunately, learning to teach critical thinking (and assessing an instructor's success teaching it) is not quite so straightforward as the outcome-based minded may think—pragmatically linking, for example, critical thinking with Bloom's Taxonomy. No matter how practical it *sounds*, this is an example of picking the wrong tool for the job. For, this approach is flawed. In *Critical thinking: What every person needs to survive in a rapidly changing world* (Chapter 31: Bloom's taxonomy and critical thinking instruction: Recall is not knowledge), the philosopher Richard W. Paul argues that while Bloom's distinctions themselves are important, the common understanding of their link to critical thinking is largely misconceived. See Talavera, I. 2006. The problem of teaching critical thinking: Three approaches. *NADE Digest* 2 (1) (Spring): 63-69.

[9]See (1) Eve, R. A., and D. Dunn. 1990. Psychic powers, astrology & creationism in the classroom? Evidence of pseudoscientific beliefs among high school biology & life science teachers. *The American Biology Teacher* 52 (1): 10-21; (2) Impey, C., S. Buxner, and J. Antonellis. 2012. Non-scientific beliefs among undergraduate students. *Astronomy Education Review*: 010111-1–010111-12; and (3) Talavera, 2016. The acquisition of scientific knowledge via critical thinking: A philosophical approach to science education. *Forum of Public Policy*, Vol 2016, No. 2.

valid scientific findings, it is likely that some teachers may not have the educational foundation necessary for recognizing pseudoscientific claims….[So, for example,] while there are many qualified and even exemplary biology teachers, the number of those who [do] not exhibit adequate scientific reasoning skills is significant enough to justify alarm.…[Moreover,] a significant proportion of high school life science and biology teachers hold many beliefs which are at odds with mainstream science…. [Thus,] many teachers are not only failing to impart basic information on the scientific method to their students, but are also likely to be misinforming students because of their own beliefs in pseudoscience.

One way to deal with this problem and help increase the public understanding and valuation of science is to engage our students **philosophically** with a call for critical thinking—principally, as each pressing scientific issue has played out in the public sphere. For instance, a classroom discussion about the problem of climate change can logically begin by questioning the much-reported evidence supporting an overwhelming scientific consensus maintaining that climate change exists and/or is due primarily to the human use of fossil fuels. Here, we see, that most in the scientific community maintain that global warming is no longer a debate.[10] Nevertheless, a wider philosophical debate that brings divergent views to the table can be encouraged in the science classroom so that intersecting arguments that war against the scientific case for urgent action to limit climate change may be **analyzed** and **evaluated**.

As we shall see, this requires, as a public-facing form of philosophy, a **critical thinking** approach[11] that when applied to claims about climate change can help the educator present a more robust picture about this life-threatening issue and deal directly and systematically with students' misconceptions and resistance to modern climate science.[12] By highlighting the critical thinking in science that (1) analyzes and evaluates arguments, and (2) engages in a form of methodological skepticism that systematically and continuously asks Critical Questions, the educator can help students actively compare their initial conceptions (and publicly popular misconceptions) with more fully scientific conceptions.

II. Intersecting problems that war against the scientific case for urgent action to limit climate change

Climate change effects may be experienced in our lifetime in the form of **ecological impacts** (e.g., The coral bleaching and acidification of the oceans projected to kill one-

[10]The Consensus Project. n.d. The debate is over (http://theconsensusproject.com/). Accessed September 8, 2019. John Cook, et al. 2013. Quantifying the consensus on anthropogenic global warming in the scientific literature. *Environ. Res. Lett.* 8 024024 (https://iopscience.iop.org/article/10.1088/1748-9326/8/2/024024). Accessed September 8, 2019.

[11]This treatise and approach is based on an application on my paper presented at Oxford University: The acquisition of scientific knowledge via critical thinking: A philosophical approach to science education. *Forum of Public Policy*, Vol 2016, No. 2, 1-66.

[12]Misconceptions and resistance need to be confronted, for instance, in Biology and Life Science courses. See Nelson, C. E. 2008. Teaching evolution (and all of biology) more effectively: strategies for engagement, critical reasoning, and confronting misconceptions. *Integrative and Comparative Biology* 48 (2): 213-225.

third of all marine life—affecting biodiversity), **agricultural impacts** (e.g., The loss of arable land due to flooding), **economic impacts** (e.g., The loss of income from arable land crops due to flooding), and **impacts on society** (e.g., The heavy migration of people displaced by flooding.). To be sure, dealing effectively with such possible dire effects demands that we look critically into the specific problems that war against the scientific case for urgent action to limit climate change.[13] For the purpose of analysis and evaluation (i.e., critical thinking), then, consider the following *conceptual map* constructed to reveal the logical space of all the possible options of the debate. We can see the overall complexity of the challenge before us as we try to wrap our minds around **three** overlapping/intersecting key sets below: $\mathbf{A}_{\mathbf{circle}}$, $\mathbf{B}_{\mathbf{circle}}$, and $\mathbf{C}_{\mathbf{circle}}$. (See **Figure 1** where **circle A** represents **The Problem of Accepting Consensus**, **circle B** represents **The Problem of Separating Skepticism from Denial**, and **circle C** represents **The Problem of Ignoring Impact**.). As we look deeper into the following options (sets/subsets) and their respective logical implications to present a more comprehensive, consistent, and unified front in our line of reasoning and call for action, we will need to focus on the different options below—voiced and/or espoused by different supporters of a pre-emptive anti-scientific stance framed in cultural, political, and/or religious terms.

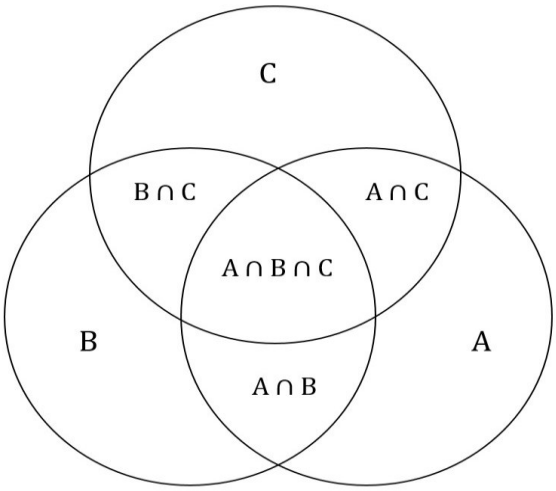

Figure 1

A. The Problem of Accepting Consensus has to do with not accepting scientific consensus—a knowledge based consensus among most scientists based on converging evidence and rigorous analysis and evaluation, which is backed-up with scrutinized peer reviewed research (that must pass the test of time after publication). For instance, some do not accept the scientific consensus that there is a link between carbon dioxide and global temperature, or, that more carbon dioxide will make a difference, or, that we can reliably determine past climate carbon dioxide levels dating back hundreds of thousands of years.

[13]For an in depth explanation about the three main obstacles to limiting climate change see **APPENDIX C**.

This may be because resistance to climate change is usually based on pseudoscientific/non-scientific beliefs, and/or on some point of view suffering from cognitive dissonance.[14]

B. The Problem of Separating Skepticism from Denial has to do with mistaking skepticism for denial. So one may, for example, simply deny a belief (doubted on the merit of some strong or fixed view held in advance) and announce to the world that this is just skepticism. For instance, one may claim to be adopting a skeptical stance by simply denying the belief that **humans are causing global warming** because one believes God controls the climate and warming is evidence that the world will be ending soon, and that we do not need to worry about global warming in light of the approaching apocalypse.[15] So, why bother *polishing the brass of a sinking ship*? Nevertheless, this **denial** is just a part of a motivated reasoning process that gathers only evidence that supports the view advanced (cherry picking and ignoring the rest). Accordingly, hard evidence as required by true skepticism is never (or can never be) provided as part of the critical thinking process seeking possible errors to correct.

C. The Problem of Ignoring Impact[16] has to do with closing your eyes to the effects of climate change in your lifetime because of the myths[17] that…

(1) **The negative effects of climate change are distant in space** (only about polar bears and penguins living at opposite ends of the world, not us) **and in time** (only about future generations, not us);[18]

(2) **We do not need to worry** (Who says climate change is such a bad thing? We are heading toward an Ice Age, so why worry about warming. There is no link between warming and extreme weather.);

(3) **Climate change is not happening** (Feels pretty cold…where is your global warming? The planet is not getting warmer. Glaciers are growing and Antarctica is gaining ice. Climate is too complex to model or predict.);

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[14]See (1) Eve, R. A., and D. Dunn. 1990. Psychic powers, astrology & creationism in the classroom? Evidence of pseudoscientific beliefs among high school biology & life science teachers. *The American Biology Teacher* 52 (1): 10-21; (2) Impey, C., S. Buxner, and J. Antonellis. 2012. Non-scientific beliefs among undergraduate students. *Astronomy Education Review*: 010111-1–010111-12; and (3) Talavera, 2016. The acquisition of scientific knowledge via critical thinking: A philosophical approach to science education. *Forum of Public Policy*, Vol 2016, No. 2.

[15]Adapted from Roser-Renouf, C., E. Maibach, A. Leiserowitz, and S. Rosenthal. 2016. *Global warming, God, and the 'end times*.' Yale University and George Mason University. New Haven, CT: Yale Program on Climate Change Communication (http://climatecommunication.yale.edu/publications/global-warming-god-end-times/). Accessed September 2, 2019.

[16]See Huddleston, N. 2013. *Climate change: evidence, impacts, and choices*. 2nd ed. National Research Council (http://dels.nas.edu/resources/static-assets/materials-based-on-reports/booklets/Climate-Change-Lines-of-Evidence.pdf). Accessed August 18, 2019.

[17]For a summary of global warming and climate change myths, sorted by recent popularity vs. what science says, see Cook, J., ed. 2017. Global warming & climate change myths. *Skeptical Science* (https://skepticalscience.com/argument.php). Accessed August 18, 2019.

[18]Adapted from UQx DENIAL101x 5.4.4.4 From the experts: Impacts on society (https://www.youtube.com/watch?v=ER0Uf-cjN6c). Accessed August 18, 2019.

(4) **It is not our fault** (It is just a natural cycle or variation—e.g., the heat energy is coming from the sun. Volcanic eruptions release greater amounts of carbon dioxide than humans do.); and,

(5) **There is nothing we can do about it** (Carbon taxes or cap-and-trade systems will destroy the economy, kill jobs, and hurt the poor. Renewable energy is too expensive or too variable. Global carbon dioxide emissions from burning fossil fuels have already exceeded the limits that some scientists believe could prevent catastrophic climate change.).[19]

III. Critical thinking applied to the claims about climate change[20]

The foregoing problems feed into the war against the scientific case for urgent action to limit climate change. Consider, for instance, a lesson plan about climate change in a science class, introducing the claim for discussion: ***Humans today are emitting prodigious quantities of CO_2, at a rate faster than even the most destructive climate changes in earth's prehistoric past***.[21] Let us begin, for instance, by setting up what is at stake by framing the issue in terms of a cogent inductive argument for the conclusion that **human made increased CO_2 does contribute to climate change**.[22]

1. Oceans absorb 90% of Earth's heat.
2. Approximately 70% of solar energy that hits Earth is absorbed and re-emitted (some of it trapped by greenhouse gases).
3. Human made CO_2 levels have increased greenhouse gases.
4. White glaciers and/or ice sheets reflect the sunlight.
5. Without sea ice, the dark open ocean absorbs sunlight and heats up, raising global temperatures, which in turn cause glaciers and ice sheets on land to melt further.
6. Melting sea ice increases heat absorbed by oceans, which causes a feed-forward cycle.

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7. Thus, human made increased CO_2 does contribute to climate change.

To be sure, we can see that the problem of teaching the science of climate change in this case has as a source people who distrust or deny Premise #3 above (**Human made**

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[19]Points 2, 3, 4, & 5 adapted from Darling, S. B., and D. L. Sisterson. 2014. *How to change minds about our changing climate*. New York: The Experiment.

[20]Here I have significantly modified and fleshed out Battersby's four basic questions from this philosopher's excellent book: *Is that a fact? A field guide to statistical and scientific information*: 1. What is being claimed? 2. How good is the evidence? 3. What other information is relevant? 4. Are relevant fallacies avoided? This approach to critical thinking and the following application are adapted from Talavera, 2016. The acquisition of scientific knowledge via critical thinking: A philosophical approach to science education. *Forum of Public Policy*, Vol 2016, No. 2, 1-66.

[21]Cook, J., ed. 2017. What does past climate change tell us about global warming? *Skeptical Science* (https://skepticalscience.com/climate-change-little-ice-age-medieval-warm-period.htm). Accessed August 18, 2019.

[22]For some of the key scientific facts used to support the premises of this argument see **APPENDIX B**.

CO_2 levels have increased greenhouse gases). Yet, there is a 97% consensus[23] among climate scientists that the earth is getting warmer[24] and sea levels are rising, and it is primarily because of humans releasing great quantities of carbon dioxide in the atmosphere. For, since the Industrial Revolution, *humans have added 2,000 gigatons of CO_2 to* [the] *atmosphere and 40% has stayed there.*[25] Because of this extra trapped greenhouse gas (coming from burning fossil fuels[26]), carbon sinks and carbon sources are out of balance.[27] *Greenhouse gases and aerosols affect climate by altering incoming solar radiation and outgoing infrared (thermal) radiation that are part of Earth's energy balance.*[28] So, just as a car left in a hot summer's day with its windows rolled-up does not allow for venting and keeps getting warmer and warmer, the earth is getting warmer and warmer.[29]

Because of this extra rise in temperature, mountain glaciers and ice sheets on land are melting. In turn, the melting ice on land contributes to sea level rise. Moreover, since white glaciers and/or ice sheets reflect the sunlight, without ice to reflect excess heat into space, the oceans absorb sunlight and heat up, further raising global temperatures. In addition, because the oceans absorb sunlight and heat up (causing a feed-forward cycle[30]), sea levels further rise due to thermal expansion of water.[31]

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[23]The Consensus Project. n.d. The debate is over (http://theconsensusproject.com/). Accessed September 8, 2019. John Cook, et al. 2013. Quantifying the consensus on anthropogenic global warming in the scientific literature. *Environ. Res. Lett.* 8 024024 (https://iopscience.iop.org/article/10.1088/1748-9326/8/2/024024). Accessed September 8, 2019.

[24]As noted in Climate science: What you need to know (https://www.youtube.com/watch?v=ffjIyms1BX4&feature=youtu.be). Accessed September 4, 2019. See sources at Science of climate change in 24 Steps (https://docs.google.com/spreadsheets/d/11E3cGmUEFouAEmxoYgd0Nn0unhz9RO6Dybip8Q9Gbew/edit#gid=0): (1) *There were twice as many record highs as record lows in 2000's and past three decades were warmest since 1850*; (2) *Average global temperatures have increased about 1˚C since 1900, and most since 1970*; and, (3) *The past 30 years is likely the warmest in eight centuries*. Accessed September 4, 2019.

[25]C. Le Quéré, et al. 2014. Global carbon budget 2013. *Earth System Science Data*, 6, 235–263 (http://bit.ly/160bj2r). Accessed September 8, 2019; World Meteorological Organization. 2014. The state of greenhouse gases in the atmosphere based on global observations through 2013. *Greenhouse Gas Bulletin* (http://bit.ly/1Btxdbp). Accessed September 4, 2019.

[26]U.S. Department of Commerce. Stable and radiocarbon isotopes of carbon dioxide. *Earth System Research Laboratory* (https://www.esrl.noaa.gov/gmd/ccgg/isotopes/c14tracer.html. Accessed September 4, 2019.

[27]IPCC. 2007. The importance of carbon sinks. *Global Carbon Project* (http://bit.ly/1uaZ0FR). Accessed September 8, 2019.

[28]IPCC. 2007. How do human activities contribute to climate change and how do they compare with natural influences? *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (http://oceanservice.noaa.gov/education/pd/climate/factsheets/howhuman.pdf). Accessed September 4, 2019.

[29]However, the whole earth does not get hotter evenly all over. Some parts of the earth will experience a huge increase in temperatures; others are going to see the exact opposite take place. See 7 INSANE effects of climate change in your lifetime (https://www.youtube.com/watch?v=7mYJ9GJMgaw). Accessed September 4, 2019.

[30]Pistone, K., I. Eisenman, and V. Ramanathan. 2014. Observational determination of albedo decrease caused by vanishing Arctic sea ice. *PNAS* (http://bit.ly/1wTFXFZ). Accessed September 2, 2019.

[31]IPCC. 2007. Is sea level rising? *IPCC Fourth Assessment Report: Climate Change 2007* (http://bit.ly/1ytK4ZX). Accessed September 4, 2019.

Such consequences can no longer be brushed aside or avoided. As Yale Climate Connections notes,

> *...melting sea ice does contribute to climate change. That's because white sea ice reflects the sun. So when it melts, the dark open ocean now absorbs sunlight and heats up, raising global temperatures, which in turn cause glaciers and ice sheets on land to melt further. Globally, sea levels have risen four to eight inches since the last century and will continue to rise as the ice melts, putting coastal communities worldwide at risk.*[32]

Nevertheless, we need not stop here. The science educator can spice up the class discussion for the sake of critical thinking and look at the popular claim that **we cannot today reliably determine past climate carbon dioxide levels dating back hundreds of thousands of years**. How do we even know how warm or cold it was in the past? **Since humans were not there in the ancient past to carry out experiments to confirm or falsify climate carbon dioxide levels**, how can scientists today know about the claimed destructive climate changes in earth's prehistoric past? Moreover, given that humans were not there in the ancient past to carry out experiments to confirm or falsify climate carbon dioxide levels, the science educator can go on to note that this may be why (increasingly), the majority of people are coming to believe that they should distrust or deny the science of climate change.

To sum up, a great opportunity for a wider philosophical debate becomes available as the class debates whether these claims are based on the problem of accepting consensus, separating skepticism from denial, and/or ignoring impact. This brings divergent views to the table so that intersecting arguments that war against the scientific case for urgent action to limit climate change may be analyzed and evaluated. Accordingly, **critical thinking**[33] may be applied to the opposing claims to help the educator present a more robust picture about this life-threatening issue and deal directly and systematically with the misconceptions and resistance to modern climate science.[34]

IV. Critical questions applied to claims about climate change

By highlighting the critical thinking in science that (1) analyzes and evaluates arguments, and (2) engages in a form of methodological skepticism that systematically and continuously asks **Critical Questions**, the educator can help students actively compare their initial conceptions (and publicly popular misconceptions) with more fully scientific

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[32]Appell, D. 2014. Loss of land ice (not sea ice) = more sea level rise. *Yale Climate Connections* (http://www.yaleclimateconnections.org/2014/11/loss-of-land-ice-not-sea-ice-more-sea-level-rise/). Accessed September 2, 2019.

[33]This approach to critical thinking is taken from Talavera, 2016. The acquisition of scientific knowledge via critical thinking: A philosophical approach to science education. *Forum of Public Policy*, Vol 2016, No. 2, 1-66.

[34]Misconceptions and resistance need to be confronted, for instance, in Biology & Life Science courses. See Nelson, C. E. 2008. Teaching evolution (and all of biology) more effectively: strategies for engagement, critical reasoning, and confronting misconceptions. *Integrative and Comparative Biology* 48 (2): 213-225.

conceptions. Accordingly, we can deal directly and systematically with the foregoing misconceptions and resistance to the science of climate change as follows.

(i) BELIEF:[35]

What is the belief? (What is the claim? What is the conclusion? What is the hypothesis?) The belief under consideration, above, is the statement/claim: **We cannot today reliably determine past climate carbon dioxide levels dating back hundreds of thousands of years**.

(ii) SKEPTICISM:[36]

Are there reasons to doubt the belief? The problem here is that for some in the general public, **paleoclimatology** and **geology**, as **historical sciences**, are typically not considered to be reliable sources of knowledge that can be regarded as more suitable than others (e.g., chemistry or physics)—as the most appropriate point of departure for scientific inquiry or confirmation. This is because humans were not there in the ancient/prehistoric past to carry out experiments to confirm or falsify the science. To be sure,

> *[h]istorical sciences like cosmology, geology, and evolutionary biology do not fit the naïve view of scientists proposing scientific theories and then carrying out experiments to confirm or falsify them. Experiments are impossible and empirical data is hard to obtain and fragmentary. However, this does not mean that these fields are not scientific, and that their theories do not need to conform to the definition of scientific theories. It does mean that predictions become retrodictions and that a long time may pass between the proposal of a theory and the availability of data to check its retrodictions*.[37]

Accordingly, we may doubt the entrenched belief (as it has played out in the public sphere) that **we cannot today reliably determine past climate carbon dioxide levels dating back hundreds of thousands of years** because one is appealing to the naïve view that scientists must all do the same things to do science. So, for instance, one may be assuming that climatologists (like all other legitimate scientists) must propose scientific theories (that can only predict effects in the future) and then carry out experiments in the present (on the basis of empirical data

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[35]For those engaged in the process of the acquisition of **scientific** knowledge, there must be the realization that our beliefs and/or opinions do not always correspond with reality (see QualiaSoup. 2013. Skewed views of science (https://www.youtube.com/watch?v=LuEO-K_-vgI). Accessed September 4, 2019.). In this light, experimental studies must be set up as a way to **critically** know reality on its own terms. Accordingly, each hypothesis can be tested for truth by means of experimentation (enter empiricism), but also justified with good arguments for believing it (enter rationalism). This helps to paint an **objective** and **logically consistent** picture of reality.

[36]See J. Schwarcz. 2012. The importance of skepticism in science. *TEDxMontrea*l (https://www.youtube.com/watch?v=YdkPt6DUKuI). Accessed September 4, 2019.

[37]Ben-Ari, *Just a theory: Exploring the nature of science*, 197.

obtainable in the present) to confirm or falsify them. Nevertheless,…*not all scientists do the same kinds of things—some experiment, others don't, some do field observations, others develop theories. Compare what chemists, theoretical physicists, zoologists, and paleontologists do.*[38]

Therefore, although it is true that humans were not there in the ancient past to carry out experiments to confirm or falsify climate carbon dioxide levels, scientists can look backward for indirect evidence so that…*predictions become retrodictions and that a long time may pass between the proposal of a theory and the availability of data to check its retrodictions*.[39]

(iii) CRITICAL THINKING (Analysis + Evaluation):

a) <u>Analysis</u>:

1. What is the argument for the belief? We can formulate the argument as the following.

(1) If humans were not there in the ancient past to carry out experiments to confirm or falsify climate carbon dioxide levels, then we cannot today reliably determine past climate carbon dioxide levels dating back hundreds of thousands of years.
(2) Humans were not there in the ancient past to carry out experiments to confirm or falsify climate carbon dioxide levels.
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(3) Thus, we cannot today reliably determine past climate carbon dioxide levels dating back hundreds of thousands of years.

2. What is the conclusion? (What is being claimed?) We cannot today reliably determine past climate carbon dioxide levels dating back hundreds of thousands of years.

3. What are the premise(s)? (What is the evidence?)

(1) If humans were not there in the ancient past to carry out experiments to confirm or falsify climate carbon dioxide levels, then we cannot today reliably determine past climate carbon dioxide levels dating back hundreds of thousands of years.

[38]Paul (with Binker), Chapter 38: Critical Thinking and Science, 612.
[39]Ben-Ari, *Just a theory: Exploring the nature of science*, 197.

(2) Humans were not there in the ancient past to carry out experiments to confirm or falsify climate carbon dioxide levels.

4. TRUTH: Are the premises true?
Premise #2 is true. Nevertheless, premise #1 is false (But, why?).

b) <u>Evaluation</u>:

1. How good is the argument? If we let **P** be **Humans were not there in the ancient past to carry out experiments to confirm or falsify climate carbon dioxide levels**; and, let **Q** be **We cannot today reliably determine past climate carbon dioxide levels dating back hundreds of thousands of years**, we can see that this is a **valid** deductive argument with the logical form called *Modus Ponens*.

(1) If **P**, then **Q**.
(2) **P**.
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(3) Thus, **Q**.

However, although the argument has a valid deductive form, **it is not sound** because premise #1 is false.

2. How good is the conclusion? (How good is the claim?)
Although the conclusion logically follows from the premises (i.e., the claim logically follows from the evidence), the conclusion /claim is false.

3. How good are the premise(s)? (How good is the evidence?)
Premise #2 is true (Humans were not there in the ancient past to carry out experiments to confirm or falsify climate carbon dioxide levels). But, premise #1 is false. Premise #1 is false because the consequent **Q** of the conditional statement *If **P**, then **Q*** is false, given that the antecedent **P** is true. Premise #1 contradicts scientific climate change research or evidence.

4. Does the argument meet the burden of proof? The argument is not consistent with the direction of climate change research or evidence. Moreover, the argument does not deal effectively with opposing evidence or arguments. Therefore, as it stands, it is not strong enough to counter this research or evidence.

For instance, as The Earth Observatory notes,

> *We know about past climates because of evidence left in tree rings, layers of ice in glaciers, ocean sediments, coral reefs, and layers of sedimentary rocks. For example, bubbles of air in glacial ice trap tiny samples of Earth's atmosphere, giving scientists a history of greenhouse gases that stretches back more than 800,000 years. The chemical make-up of the ice provides clues to the average global temperature.*[40]

Accordingly, we can argue for the claim **that scientists can reliably determine past climate carbon dioxide levels dating back hundreds of thousands of years** as follows.

> (1) Tree rings provide reliable evidence about past climates.
> (2) Layers of ice in glaciers provide reliable evidence about past climates.
> (3) Ocean sediments provide reliable evidence about past climates.
> (4) Coral reefs provide reliable evidence about past climates.
> (5) Layers of sedimentary rocks provide evidence about past climates.
> (6) Ancient rodent waste can give scientists an insight into how climate changed over time.
> (7) Ice cores of ancient ice can reliably tell us about past climates.
> ---
> (8) Thus, scientists have access to reliable knowledge about past climates.
> ---
> (9) Therefore, scientists can reliably determine past climate carbon dioxide levels dating back hundreds of thousands of years.

It is important to note that each premise above can invoke its own sub-argument to bolster the particular evidence it provides. So, for instance, premise #2 above can invoke its own argument to support the particular evidence that **Layers of ice in glaciers provide reliable evidence about past climates**. Consider, for example, the following sub-argument.

> (1) Bubbles of air in glacial ice trap tiny samples of Earth's atmosphere, giving scientists a history of greenhouse gases that stretches back more than 800,000 years.

[40]The Earth Observatory. 2010. How is today's warming different from the past? *EOS Project Science Office, NASA Goddard Space Flight* Center (https://earthobservatory.nasa.gov/features/GlobalWarming/page3.php). Accessed September 4, 2019.

(2) The chemical make-up of the ice provides clues to the average global temperature.

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(3) Thus, layers of ice in glaciers provide reliable evidence about past climates.

5. Is there relevant information that is missing? Here, we can now see that our original *Modus Ponens* argument subject to evaluation in part b (sect. #1) ignores or dismisses the relevant context or background information about **how scientists determine past climate**.[41]

6. Are relevant fallacies avoided? Given that humans were not there in the ancient past to carry out experiments to confirm or falsify climate carbon dioxide levels, one may go on to note that this is why increasingly, the majority of people are coming to believe that they should distrust or deny the science of climate change. Nevertheless, such an argument amounts to appealing to a growing segment of the population that believes it is popular to deny climate change. This popularity is used as the reason to establish a case against climate change science.

Accordingly, one is committing **The Bandwagon Fallacy**. Such an argument is fallacious for the reason that just because someone believes something is a current fad and trend (because, for example, of *peer pressure, political expediency, or even plain mass stupidity*[42]), an appeal to the meager fact that an idea is fashionable as evidence does not make the idea true. Therefore, for example, one may be taken to be arguing that

(1) Increasingly, the majority of people are coming to believe that the science of climate change should be distrusted or denied.

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(2) Therefore, the science of climate change should be distrusted or denied.

However, such an argument is fallacious because popularity (presented as evidence) does not guarantee the validity of an argument. So, although the premise of this argument is true, the conclusion is false. Accordingly, the **invalid argument form** for this line of reasoning can be displayed as the following (Let **X** be **statement**).

[41]Such relevant information may be gleaned from the sources listed in **APPENDIX D**.
[42]Logical Fallacies. 2019. Bandwagon fallacy (http://www.logicalfallacies.info/relevance/bandwagon/). Accessed September 4, 2019.

(1) Increasingly, the majority of people are coming to believe that **X**.

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(2) Therefore, **X**.

The invalidity of this argument is clearly discernable when we let **X** be statements, for example, like **Santa Claus exists**, **Slavery is good**, **The earth is flat**, etc.

V. Conclusion

In this treatise, we looked at the problem of teaching the science of climate change and a call for critical thinking applied to this pressing issue as it has played out in the public sphere. I have shown that science educators can engage students **philosophically** with a distinctive methodology that incorporates critical thinking. Specifically, this approach can be applied to claims about climate change to help the science educator present a more robust picture about this life-threatening issue and deal directly and systematically with students' misconceptions and resistance to modern climate science. This is one way to help increase public understanding and valuation of science.

However, teaching critical thinking is like throwing high-level cognitive *bricks* at a glass window (our students). The glass window has the tendency to break—just like our students who have the inborn critical thinking skills waiting to be revealed. Yet, this latent property is not revealed until the window is hit with the sometimes *overly heavy-handed and, at points, offensive* brick. Accordingly, to teach critical thinking effectively,[43] we need to be *disturbers of the peace*.[44] This means that to get a person to develop his/her critical thinking skills to think ***outside the box***, we must work to overcome dogmatic beliefs, hardened biases, and motivated and/or distorted reasoning.[45]

But the problem does not end with our students, for some science teachers are failing their pupils by not challenging claims for or against climate change when they come up during lessons on climate science. Nevertheless, **critical thinking**[46] can be applied to claims about climate change so that the educator may also develop a more robust understanding about this contemporary issue and deal directly and systematically with students' misconceptions and resistance to modern climate science. This, as I have shown, can be achieved by highlighting the critical thinking in science that (1) analyzes and

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[43]Talavera, I. 2006. The problem of teaching critical thinking: Three approaches. *NADE Digest* 2 (1) (Spring): 63-69.

[44]The philosopher Baruch Spinoza (1632-1677) once declared *I do not know how to teach philosophy without becoming a disturber of the peace*.

[45]See **Fleas in a Jar** (http://www.bing.com/videos/search?q=fleas+in+the+jar&&view=detail&mid=7DE325BF72A055DA9A327DE325BF72A055DA9A32&rvsmid=39840B7432CE26B3023239840B7432CE26B30232&FORM=VDFSRV&fsscr=0). Accessed September 4, 2019.

[46]See the **REFERENCES** and **APPENDICES A, B, C, AND D** for resources science educators can use with the Critical Questions in their classes.

evaluates arguments, and (2) engages in a form of methodological skepticism that systematically and continuously asks Critical Questions.

In short, by engaging in a wider philosophical debate that brings divergent views to the table via critical thinking, both the science educator and his/her students can actively compare their initial conceptions (and publicly popular misconceptions) with more fully scientific conceptions. Therefore, there is a genuine educational benefit to teaching climate science as critical thinking. For, this approach may offset one's pre-emptive anti-scientific stance framed in cultural, political, and/or religious terms.[47]

[47]See Talavera, I. 2016. The Acquisition of Scientific Knowledge via Critical Thinking: A Philosophical Approach to Science Education. *Forum of Public Policy*, Vol 2016, No. 2.

APPENDIX A: Web Video Resources for the Science Class

The science behind climate change may be gleaned from the following videos (All Accessed August 28, 2019).

1. Climate Science

Climate Science: What You Need To Know
(https://www.youtube.com/watch?v=ffjIyms1BX4&feature=youtu.be).

What's REALLY Warming the Earth?
(https://www.youtube.com/watch?v=hphdsLcSTYQ).

13 Misconceptions About Global Warming
(https://www.youtube.com/watch?v=OWXoRSIxyIU)

UQx DENIAL101x 3.2.1.1 Upsetting the natural balance
(https://www.youtube.com/watch?v=FlIJTJWP6PQ).

Demystifying ocean acidification and biodiversity impacts
(https://www.youtube.com/watch?v=GL7qJYKzcsk).

UQx DENIAL101x 4.2.1.1 Message from the past
(https://www.youtube.com/watch?v=H5kejSYPD7U).

UQx DENIAL101x 2.3.3.1 Antarctic land ice vs sea ice
(https://www.youtube.com/watch?v=9PUmKHBtnlA).

UQx DENIAL101x 2.4.4.1 Climate change vs global warming
(https://www.youtube.com/watch?v=HAF9jl6fupA).

UQx DENIAL101x 3.2.2.1 Human CO_2 emissions trump volcanoes'
(https://www.youtube.com/watch?v=cy9rx19dujU).

UQx DENIAL101x 4.2.1.1 Modern vs. past climate change
(https://www.youtube.com/watch?v=kzwyfnq_u5c).

UQx DENIAL101x 4.4.2.1 Climate model success stories
(https://www.youtube.com/watch?v=qJGVvLO2FcU).

UQx DENIAL101x 1.7.1.1. Full interview with Ben Santer
(https://www.youtube.com/watch?v=EOrUYQhGzT8).

2. Connecting the Dots

Neil deGrasse Tyson scolds cherry picking climate science
https://www.youtube.com/watch?v=y1MZ8U8C9c8

One climate change scientist takes on a roomful of sceptics.
https://www.youtube.com/watch?v=6hCRafyV0zI

EXPLORER: Bill Nye's Global Meltdown
(https://vimeo.com/144908349).

Game On, Climate Change. Game On. | Laura Tenenbaum | TEDxUCSD
(https://www.youtube.com/watch?v=IqEhkzQeoCc).

The Scientific Case for Urgent Action to Limit Climate Change
(https://www.youtube.com/watch?v=B4Q271UaNPo).

Global Warming The Signs and the Science. Climate Change
(https://www.youtube.com/watch?v=nVD-Wt-OGOg).

Climate Change the Crisis Part One ★ Climate Change Documentary HD
(https://www.youtube.com/watch?v=bfQ5gjUpnz0).

Discovery Channel Global Warming, What You Need To Know, with Tom Brokaw 2
(https://www.youtube.com/watch?v=2GI74ukNpTA).

APPENDIX B: Web Video Resources for the Science Class

Some of the key applicable scientific facts used to support the premises of the argument are summarized as follows (All accessed September 1, 2019).[48]

1. ~70% of solar energy that hits Earth is absorbed and re-emitted, some of it trapped by greenhouse gases
(https://earthobservatory.nasa.gov/features/EnergyBalance/page7.php).

2. Without greenhouse effect, Earth would be ~33˚C colder
(http://whatsyourimpact.org/greenhouse-effect).

3. CO_2 levels have increased 40% since Industrial Revolution
(http://www.wmo.int/pages/prog/arep/gaw/ghg/documents/GHG_Bulletin_10_Nov2014_EN.pdf).

[48]As noted at *Science of Climate Change in 24 Steps* [Note: the 8th step and some web sources have been updated]
(https://docs.google.com/spreadsheets/d/11E3cGmUEFouAEmxoYgd0Nn0unhz9RO6Dybip8Q9Gbew/edit#gid=0). Accessed September 1, 2019.

4. Solar activity and temperature show opposite trends in recent decades (https://skepticalscience.com/solar-activity-sunspots-global-warming.htm).

5. The lower atmosphere is warming while the upper atmosphere is cooling (http://www.pnas.org/content/110/1/26.full.pdf; http://www.climatecentral.org/news/new-evidence-of-human-fingerprints-on-global-warming-15316).

6. Humans have added 2,000 gigatons of CO_2 to atmosphere since 1870, and 40% has stayed there (http://www.earth-syst-sci-data.net/6/235/2014/essd-6-235-2014.pdf; https://www.epa.gov/ghgemissions/overview-greenhouse-gases).

7. CO_2 levels haven't been this high (>400 ppm) since before humans existed (http://www.climatecentral.org/news/the-last-time-co2-was-this-high-humans-didnt-exist-15938).

8. Earth is warming 50x faster than when it comes out of an ice age (https://www.theguardian.com/environment/climate-consensus-97-per-cent/2016/feb/24/earth-is-warming-is-50x-faster-than-when-it-comes-out-of-an-ice-age).

9. Carbon isotopes tell us that increased CO_2 is coming from burning fossil fuels (https://www.esrl.noaa.gov/gmd/outreach/isotopes/stable.html).

10. Volcanoes are not the source of modern climate change (https://volcanoes.usgs.gov/vhp/gas.html).

11. Carbon sinks and carbon sources are out of balance (http://shrinkthatfootprint.com/wp-content/uploads/2013/05/Concentrations1.jpg).

12. Methane and nitrous oxide are increasing (also due to human activities) (http://oceanservice.noaa.gov/education/pd/climate/factsheets/howhuman.pdf).

13. Climate models are unable to replicate warming trend unless manmade CO_2 is taken into account (https://skepticalscience.com/climate-models-intermediate.htm).

14. There were twice as many record highs as record lows in 2000's and past three decades were warmest since 1850 (https://www.ncdc.noaa.gov/sotc/global/201513; https://www.climate.gov/news-features/featured-images/past-three-decades-warmest-record).

15. Average global temperatures have increased about 1˚C since 1900, and most since 1970 (https://www.ncdc.noaa.gov/sotc/global/201513).

16. The past 30 years is likely the warmest in eight centuries (http://www.ipcc.ch/report/ar5/\).

17. Oceans absorb 90% of Earth's heat (http://www.realclimate.org/index.php/archives/2013/09/what-ocean-heating-reveals-about-global-warming/).

18. Sea levels have risen ~8 inches since 1901, and are rising 0.1 inches per year (http://www.ucsusa.org/global_warming/science_and_impacts/impacts/infographic-sea-level-rise-global-warming.html#.WKAAFPkrJD-).

19. Sea levels rise due to thermal expansion of water (http://www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-5-1.html).

20. Melting ice on land contributes to sea level rise (not melting sea ice) (http://www.yaleclimateconnections.org/2014/11/loss-of-land-ice-not-sea-ice-more-sea-level-rise/).

21. CO_2 dissolving in ocean drives ocean acidification (https://www.nrdc.org/stories/what-you-need-know-about-ocean-acidification?gclid=COKJzsv4idICFU86gQodVdQIug).

22. Oceans could hit pH 7.8 in 100 years (http://www.whoi.edu/main/topic/ocean-acidification; http://takvera.blogspot.com/2012/03/ocean-acidification-increasing-at.html).

23. Summer sea ice levels have decreased 40% since 1978 (http://nca2014.globalchange.gov/report/our-changing-climate/melting-ice).

24. Melting sea ice increases heat absorbed by oceans, which causes a feed-forward cycle (http://www.pnas.org/content/111/9/3322.abstract).

APPENDIX C: Web Video Resources for the Science Class

An in depth explanation about the three main obstacles to limiting climate change may be gleaned from the following videos (All accessed September 1, 2019).

A. <u>The Problem of Accepting Consensus</u>:

UQx DENIAL101x 1.2.6.1 From the experts: Scientific consensus (https://www.youtube.com/watch?v=tU_aMg73h90).

UQx DENIAL101x 1.2.4.1 Knowledge Based Consensus (https://www.youtube.com/watch?v=HUOMbK1x7MI).

UQx DENIAL101x 1.2.1.1 Consensus of Evidence (https://www.youtube.com/watch?v=5LvaGAEwxYs).

UQx DENIAL101x 1.2.2.1 Consensus of Scientists (https://www.youtube.com/watch?v=WAqR9mLJrcE).

UQx DENIAL101x 1.2.3.1 Consensus of Papers (https://www.youtube.com/watch?v=LdLgSirToJM).

B. <u>The Problem of Separating Skepticism from Denial</u>:

Dr Richard Milne - Critical Thinking on Climate Change: Separating Skepticism from Denial (https://www.youtube.com/watch?v=gh9kDCuPuU8).

Why People Don't Believe In Climate Science (https://www.youtube.com/watch?v=y2euBvdP28c).

UQx DENIAL101x 1.3.5.2 From the experts: Skepticism vs Denial (https://www.youtube.com/watch?v=--pyeRHCpRM).

UQx DENIAL101x 1.4.3.1 Five Characteristics of Science Denial (https://www.youtube.com/watch?v=wXA777yUndQ).

UQx DENIAL101x 1.4.5.1 From the experts: Spread of denial (https://www.youtube.com/watch?v=OjMx7dFZsr4).

UQx DENIAL101x 1.3.2.1 Ideological Bias (https://www.youtube.com/watch?v=nj1-tDKuHno).

UQx DENIAL101x 1.4.2.1 Media Balance as Bias (https://www.youtube.com/watch?v=YdUVe0kd24A).

UQx DENIAL101x From the Experts: Attack on Science (https://www.youtube.com/watch?v=aeSNhayqGcI).

UQx DENIAL101x 1.3.3.1 Psychological Barriers to Concern about Climate Change (https://www.youtube.com/watch?v=b3mxyFGjelA).

Climate change -- the greatest story never told | George Marshall | TEDxWWF (https://www.youtube.com/watch?v=wBlTu9Tpvvo).

UQx DENIAL101x 1.3.1.1 Vested Interests (https://www.youtube.com/watch?v=8i-fDTeHyd8).

UQx DENIAL101x 1.4.1.1 Manufacturing Doubt (https://www.youtube.com/watch?v=uhykhXxjzGE).

Is Climate Denial Destroying Our Planet? (Feat. Michael Mann) (December 2016) (https://www.youtube.com/watch?v=UV4YsfpSGgM).

C. <u>The Problem of Ignoring Impact</u>:

The reality of climate change | David Puttnam | TEDxDublin
(https://www.youtube.com/watch?v=SBjtO-0tbKU).

The Sixth Extinction
(https://www.youtube.com/watch?v=z9gHuAwxwAs).

10 Signs That GLOBAL WARMING Is NO LONGER A Debate
(https://www.youtube.com/watch?v=tCWI-2aISoc).

7 INSANE Effects of Climate Change in Your Lifetime
(https://www.youtube.com/watch?v=7mYJ9GJMgaw).

UQx DENIAL101x 5.4.4.4 From the experts: Impacts on society
(https://www.youtube.com/watch?v=ER0Uf-cjN6c).

UQx DENIAL101x 5.3.5.1b From the experts: Coral bleaching and Acidification
(https://www.youtube.com/watch?v=aYrLSrgWu0Y).

UQx DENIAL101x 5.4.3.1 Agricultural impacts
(https://www.youtube.com/watch?v=wcDUaBO8T34).

UQx DENIAL101x 5.3.5.1 From the experts: Ecological impacts
(https://www.youtube.com/watch?v=9nThLNcXkWg).

Do The Math - The Movie
(https://www.youtube.com/watch?v=IsIfokifwSo).

Guy McPherson on Global Warming
(https://www.youtube.com/watch?v=CIRqgwGV6I0)

APPENDIX D: Resources for the Science Class to Understand How Scientists Determine Past Climate

Articles/Reports:

National Academy of Sciences, Engineering, and Medicine and The Royal Society. 2014. *Climate change: Evidence and causes*. Washington, D.C.: The National Academies Press (https://nas-sites.org/americasclimatechoices/more-resources-on-climate-change/climate-change-evidence-and-causes/). Accessed September 1, 2019.

National Institute of Water and Atmospheric Research. 2016. How do we determine past climate? *New Zealand Government Crown Research Institute*

(https://www.niwa.co.nz/climate/faq/how-do-we-determine-past-climate). Accessed September 1, 2019.

Sjøgren, K. 2015. Scientists discover the cause behind prehistoric climate change: Scientists now know why the climate underwent dramatic changes at the end of the last Ice Age. *Science Nordic* (https://sciencenordic.com/climate-denmark-earth/scientists-discover-the-cause-behind-prehistoric-climate-change/1425435). Accessed September 4, 2019.

References

AMAP. 2019. AMAP climate change update 2019: An update to key findings of snow, water, ice and permafrost in the Arctic (https://www.amap.no/documents/doc/AMAP-Climate-Change-Update-2019/1761). Accessed September 1, 2019.

Anthes, R.A., R.W. Corell, G., Holland, J.W. Hurrell, M.C. MacCracken, and K. Trenberth. 2006. Hurricanes and global warming—Potential linkages and consequences. *Bulletin of the American Meteorological Society*, 87: 623-628 (https://journals.ametsoc.org/doi/pdf/10.1175/BAMS-87-5-617). Accessed September 1, 2019.

Appell, D. 2014. Loss of land ice (not sea ice) = more sea level rise. *Yale Climate Connections* (http://www.yaleclimateconnections.org/2014/11/loss-of-land-ice-not-sea-ice-more-sea-level-rise/). Accessed September 2, 2019.

Bassham, G., W. Irwin, H. Nardone, and J. M. Wallace. 2008. *Critical thinking: A student's introduction.* 3rd ed. New York: McGraw-Hill.

Battersby, M. 2010. *Is that a fact? A field guide to statistical and scientific information*. Ontario: Broadview Press.

Ben-Ari, M. 2005. *Just a theory: Exploring the nature of science*. Amherst: Prometheus Books.

Bricker, L., and P. Bell. 2009. Conceptualizations of argumentation from science studies and the learning sciences and their implications for the practices of science education. *Science Education* 92: 473-498.

Caste, N. J., and J. H. Kiersky. 1995. *Thinking critically: Techniques for logical reasoning*. St. Paul: West Publishing Co.

Climate Central. 2012. *Global weirdness: severe storms, deadly heat waves, relentless drought, rising seas, and the weather of the future*. New York: Vintage Books.

Cook, J., ed. 2017. Global warming & climate change myths. *Skeptical Science*

(https://skepticalscience.com/argument.php). Accessed September 2, 2019.

Cook, J., ed. 2017. What does past climate change tell us about global warming? *Skeptical Science* (https://skepticalscience.com/climate-change-little-ice-age-medieval-warm-period.htm). Accessed September 2, 2019.

Cook, J., et al. 2013. Quantifying the consensus on anthropogenic global warming in the scientific literature. *Environ. Res. Lett.* 8 024024 (https://iopscience.iop.org/article/10.1088/1748-9326/8/2/024024). Accessed September 8, 2019.

Darling, S. B., and D. L. Sisterson. 2014. *How to change minds about our changing climate*. New York: The Experiment.

Easton, T. A., ed. 2009. *Taking sides: Clashing views in science, technology, and society.* 8th ed. New York: McGraw-Hill.

Ede, A. 2000. Has science education become an enemy of scientific rationality? *Skeptical Inquirer* 24: 48-51.

Epstein, R. L., and C. Kernberger. 2006. *The pocket guide to critical thinking*. Belmont: Wadsworth.

Eve, R. A., and D. Dunn. 1990. Psychic powers, astrology & creationism in the classroom? Evidence of pseudoscientific beliefs among high school biology & life science teachers. *The American Biology Teacher* 52 (1): 10-21.

Forrest, B., and P. R. Gross. 2005. The wedge of intelligent design: Retrograde science, schooling, and society. *Scientific values and civic virtues*, ed. N. Koertge. New York: Oxford Univ. Press.

Funk, C., and L. Rainie. 2015. Public and scientists' views on science and society. *Pew Research Center* (http://www.pewinternet.org/2015/01/29/public-and-scientists-views-on-science-and-society/). Accessed September 5, 2019.

Goldfarb, T., and M. Pritchard. 1999. Ethics in the science classroom: An instructional guide for secondary school science teachers. *ENC Focus: A Magazine for Classroom Innovators* 8(3), Online Ethics Center for Engineering (http://www.onlineethics.org/Resources/precollege/scienceclass.aspx). Accessed: September 4, 2019.

Grant, J. 2011. *Denying science: Conspiracy theories, media distortions, and the war against reality.* Amherst: Prometheus Books.

Gross, P. R., and N. Levitt. 1994. *Higher superstition: The academic left and its quarrels with science*. Baltimore: The John Hopkins University Press.

Huddleston, N. 2013. *Climate change: evidence, impacts, and choices*. 2nd ed. National Research Council (http://dels.nas.edu/resources/static-assets/materials-based-on-reports/booklets/Climate-Change-Lines-of-Evidence.pdf). Accessed August 18, 2019.

Impey, C., S. Buxner, and J. Antonellis. 2012. Non-scientific beliefs among undergraduate students. *Astronomy Education Review*: 010111-1–010111-12.

Intergovernmental Panel on Climate Change. 2007. How do human activities contribute to climate change and how do they compare with natural influences? *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (http://oceanservice.noaa.gov/education/pd/climate/factsheets/howhuman.pdf). Accessed September 4, 2019.

Intergovernmental Panel on Climate Change. 2007. Is sea level rising? *IPCC Fourth Assessment Report: Climate Change 2007* (http://bit.ly/1ytK4ZX). Accessed September 2, 2019.

Intergovernmental Panel on Climate Change. 2007. The importance of carbon sinks. *Global Carbon Project* (http://bit.ly/1uaZ0FR). Accessed September 8, 2019.

Intergovernmental Panel on Climate Change. 2014. Climate change 2014: Synthesis report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. *IPCC* (http://www.ipcc.ch/report/ar5/syr/). Accessed September 2, 2019.

Johnson, M., and M. Pigliucci. 2004. Is knowledge of science associated with higher skepticism of pseudoscientific claims? *The American Biology Teacher* 66 (8): 536-548.

Joint Science Academies. 2005. Joint science academies' statement: Global response to climate change (http://www.nationalacademies.org/onpi/06072005.pdf). Accessed September 2, 2019.

Kuhn, D. 1993. Science as argument: implications for teaching and learning scientific thinking. *Science Education* 77 (3): 319-337.

Kuhn, D. 2010. Teaching and learning science as argument. *Science Education* 94: 810-824.

Le Quéré, C., et al. 2014. Global carbon budget 2013. *Earth System Science Data*, 6, 235–263 (http://bit.ly/160bj2r). Accessed September 8, 2019.

Lee, J. A. 2000. *The scientific endeavor: A primer on scientific principles and*

practice. San Francisco: Addison Wesley Longman.

Logical Fallacies. 2019. Bandwagon fallacy (http://www.logicalfallacies.info/relevance/bandwagon/). Accessed September 4, 2019.

Marshall, G. 2014. *Don't even think about it: Why our brains are wired to ignore climate change*. New York: Bloomsbury Press.

Mayfield, M. 2001. *Thinking for yourself: Developing critical thinking skills through reading and writing*. USA: Thomson Learning, Inc.

Momsen, J. L., T. M. Long, S. A. Wyse, and D. Ebert-May. 2010. Just the facts? Introductory undergraduate biology courses focus on low-level cognitive skills. *CBE—Life Sciences Education* 9: 435-440.

Moore, B. N., and R. Parker. 2015. *Critical thinking*. New York: McGraw-Hill, Inc.

National Academy of Sciences, Engineering, and Medicine. 2017. *Valuing climate damages: Updating estimation of the social cost of carbon dioxide.* Washington, D.C.: The National Academies Press (https://www.nap.edu/catalog/24651/valuing-climate-damages-updating-estimation-of-the-social-cost-of). Accessed September 2, 2019.
.

National Academy of Sciences, Engineering, and Medicine and The Royal Society. 2014. *Climate change: Evidence and causes*. Washington, D.C.: The National Academies Press (https://nas-sites.org/americasclimatechoices/more-resources-on-climate-change/climate-change-evidence-and-causes/). Accessed September 1, 2019.

National Center for Atmospheric Research. 2006. *Changes in solar brightness too weak to explain global warming*. Science Daily. (www.sciencedaily.com/releases/2006/09/060914095559.htm). Accessed September 2, 2019.

National Institute of Water and Atmospheric Research. 2016. How do we determine past climate? *New Zealand Government Crown Research Institute* (https://www.niwa.co.nz/climate/faq/how-do-we-determine-past-climate). Accessed September 1, 2019.

National Research Council. 2012. *Climate change: Evidence, impacts, and choices: PDF booklet*. Washington, DC: The National Academies Press (https://www.nap.edu/catalog/14673/climate-change-evidence-impacts-and-choices-pdf-booklet). Accessed September 5, 2019.

Nelson, C. E. 2008. Teaching evolution (and all of biology) more effectively: strategies

for engagement, critical reasoning, and confronting misconceptions. *Integrative and Comparative Biology* 48 (2): 213-225.

Oreskes, N., and E. M. Conway. 2010. *Merchants of doubt: How a handful of scientists obscured the truth on issues from tobacco smoke to global warming*. New York: Bloomsbury Press.

Paul, R. W. 2012. *Critical thinking: What every person needs to survive in a rapidly changing world.* Tomales: Foundation for Critical Thinking.

Pew Research Center. 2015. Public and scientists' views on science and society. *Pew Research Center* (https://www.pewresearch.org/science/2015/01/29/publicand-scientists-views-on-science-and-society/). Accessed September 2, 2019.

Pistone, K., I. Eisenman, and V. Ramanathan. 2014. Observational determination of albedo decrease caused by vanishing Arctic sea ice. *PNAS* (http://bit.ly/1wTFXFZ). Accessed September 2, 2019.

QualiaSoup. 2013. Skewed views of science (https://www.youtube.com/watch?v=LuEO-K_-vgI). Accessed September 4, 2019.

Ramanathan, V., and Y. Feng. 2008. On avoiding dangerous anthropogenic interference with the climate system: Formidable challenges ahead. *Proceedings of the National Academy of Sciences*, 105(38), 14245-14250 (http://www.pnas.org/content/105/38/14245.full.pdf). Accessed September 2, 2019.

Riebeek, H. 2010. Global warming. *Earth Observatory* (http://earthobservatory.nasa.gov/Features/GlobalWarming/). Accessed September 2, 2019.

Roser-Renouf, C., E. Maibach, A. Leiserowitz, and S. Rosenthal. 2016. *Global warming, God, and the 'end times*.' Yale University and George Mason University. New Haven, CT: Yale Program on Climate Change Communication (http://climatecommunication.yale.edu/publications/global-warming-god-end-times/). Accessed September 2, 2019.

Rowe, M. P., B. M. Gillespie, K. R. Harris, S. D. Koether, L. Y. Shannon, and L. A. Rose. 2015. Redesigning a general education science course to promote critical thinking. *CBE—Life Sciences Education* 14 (Fall): 1-12.

Sagan, C. 1996. *The demon-haunted world: Science as a candle in the dark.* New York: Ballantine.

Schick Jr., T., and L. Vaughn. 2008. *How to think about weird things: Critical thinking for a new age*. 5th ed. New York: McGraw-Hill.

Schwarcz, J. 2012. The importance of skepticism in science. *TEDxMontrea*l (https://www.youtube.com/watch?v=YdkPt6DUKuI). Accessed September 4, 2019.

Sjøgren, K. 2015. Scientists discover the cause behind prehistoric climate change: Scientists now know why the climate underwent dramatic changes at the end of the last Ice Age. *Science Nordic* (http://sciencenordic.com/scientists-discover-cause-behind-prehistoric-climate-change). Accessed September 1, 2019.

Talavera, I. 2006. The problem of teaching critical thinking: Three approaches. *NADE Digest* 2 (1) (Spring): 63-69.

Talavera, I. 2011. Beyond ethical codes: A call for critical thinking in religious culture. *The Forum on Public Policy,* Vol 2011, 1-14.

Talavera, I. 2012. Science and religion: Drawing the line. *The Forum on Public Policy,* Vol 2012, 1-25.

Talavera, I. 2013. The fallacy of misplaced temporality in western philosophy, natural science and theistic religion. *The Forum on Public Policy*, Vol 2013, 1-46.

Talavera, I. 2016. The acquisition of scientific knowledge via critical thinking: A philosophical approach to science education. *Forum of Public Policy*, Vol 2016, No. 2, 1-66.

The Consensus Project. n.d. The debate is over (http://theconsensusproject.com/). Accessed September 8, 2019.

The Earth Observatory. 2010. How is today's warming different from the past? *EOS Project Science Office, NASA Goddard Space Flight* Center (https://earthobservatory.nasa.gov/features/GlobalWarming/page3.php). Accessed September 4, 2019.

Union of Concerned Scientists. 2018. Scientists agree: Global warming is happening and humans are the primary cause (https://www.ucsusa.org/global-warming/science-and-impacts/science/scientists-agree-global-warming-happening-humans-primary-cause). Accessed September 2, 2019.

Union of Concerned Scientists. 2018. The science connecting extreme weather to climate change (https://www.ucsusa.org/our-work/global-warming/science-and-impacts/climate-attribution-science#.Wxp_fEiUuUk). Accessed September 8, 2019.

U.S. Climate Change Science Program. 2006. Temperature trends in the lower atmosphere: Steps for understanding and reconciling differences. *Executive Summary* (https://www.gfdl.noaa.gov/bibliography/related_files/tmlw0602.pdf). Accessed September 2, 2019.

U.S. Climate Change Science Program. 2008. The effects of climate change on agriculture, land resources, water resources, and biodiversity in the United States. (https://www.usda.gov/oce/climate_change/SAP4_3/CCSPFinalReport.pdf). Accessed September 2, 2019.

U.S. Department of Commerce. n.d. Stable and radiocarbon isotopes of carbon dioxide. *National Oceanic and Atmospheric Administration: Earth System Research Laboratory: Global Monitoring Division* (https://www.esrl.noaa.gov/gmd/ccgg/isotopes/c14tracer.html). Accessed September 12, 2019.

U.S. Environmental Protection Agency. 2016. (https://www.epa.gov/climate-indicators). Accessed September 2, 2019.

U.S. Geological Survey. 2016. Volcanic gases and their effects. *Volcano Hazards Program* (https://volcanoes.usgs.gov/vhp/gas.html). Accessed September 2, 2019.

Walker, W. R., S. J. Hoekstra, and R. J. Vogl. 2002. Science education is no guarantee of skepticism. *Skeptic* 9: 24-27.

Weston, A. 2000. *A rulebook for arguments.* 3rd ed. Indianapolis: Hackett Publishing Co., Inc.

World Meteorological Organization. 2014. The state of greenhouse gases in the atmosphere based on global observations through 2013. *Greenhouse Gas Bulletin* (http://bit.ly/1Btxdbp). Accessed September 4, 2019.