Extreme Weather Events and the Climate Crisis: What is the Connection?

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Abstract

Students face many challenges that are connected to the scientific enterprise, such as the increasing frequency of extreme weather events (e.g., prolonged periods of drought, record temperatures, severe precipitation episodes). Recent scientific consensus has attributed increases in such events to the current climate crisis caused by human activities. The potential relation between extreme weather and current climate change characterizes why these phenomena may be complex, and understanding both the distinctions and relations between weather and climate is essential for reasoning about such phenomena. To help students in this regard, we have designed the Extreme Weather build-a-MEL, where they evaluate the connections between lines of evidence and alternative explanations. The build-a-MEL helps increase students' agency (i.e., to intentionally make things happen through actions). And with increased agency, students are able to construct knowledge about weather and climate through engagement in scientific practices, with alignment to the *Next Generation Science Standards*.

Students are often confused about the difference between weather and climate. For example, students may think that short-term weather trends indicate long-term climate patterns (Lombardi & Sinatra, 2012). Adults may also share this confusion about weather and climate differences. During a 2010 blizzard in the Washington D.C. area, some politicians used this extreme snowfall event as evidence supporting the nonscientific notion that climate change is a hoax. However, a single weather event, such as this blizzard, is not an indicator—in and of itself—of current climate change. Students' and adults' confusion about the distinctions between weather and climate may point toward the need for increased climate science literacy. A report by the U.S. Global Change Research Program (USGCRP) said, among other things, that "a climate-literate person (a) understands the essential principles of Earth's climate system and (b) knows how to assess scientifically credible information about climate" (USGCRP, 2009, p. 4). The report specifically points out that "Climate is not the same thing as weather. Weather is the minute-by-minute variable condition of the atmosphere on a local scale. Climate is a conceptual description of an area's average weather conditions and the extent to which those conditions vary over long time intervals" (USGCRP, 2009, p. 13). And yet, the idea of climate as simple "average weather conditions" may also contribute to misunderstanding between weather and climate.

Climate conditions are more precisely established by statistical trends in weather conditions and other factors (e.g., extremes such as record maxima and minima temperatures and precipitation in addition to averages). Climate is also characterized by considering these statistical trends over relatively long periods of time in a given region. The U.S. National Oceanic and Atmospheric Administration (NOAA) says that "climate normals" reflect averages of precipitation, temperature, humidity, sunshine, wind, and other measures of weather that occur over a 30-year period (NOAA, 2018). Scientists also use extreme temperature and precipitation events, as well as droughts and frequency of very severe events (e.g., tornadoes, hurricanes), to characterize an area's climate. Thus, climate represents a wide variety of weather-related statistics that involve different phenomena over relatively long time scales, whereas weather involves short duration (minutes, hours, days, and months) atmospheric events at a particular location (Lombardi & Sinatra, 2012).

Because of both statistical and scientific complexities, learning about the differences between weather and climate may be difficult for students. Instructional scaffolds that help students with these various complexities, however, may facilitate their learning. This article discusses the use of a Model-Evidence Link (MEL) scaffold, which we developed around the concept of extreme weather events and potential relations to the current climate crisis. We have specifically designed this MEL scaffold to help students evaluate the connections between lines of scientific evidence and alternative explanations about the extreme weather phenomena. Table 1 shows how this extreme weather instructional scaffold is well-aligned with some Performance Expectations (PEs) found in the *Next Generation Science Standards* (NGSS Lead States, 2013).

Table 1. ***Next Generation Science Standards (NGSS)*** **Performance Expectations (PE) Related to the Extreme Weather Build-a-MEL**

PE Code	PE Description
MS-ESS3-2	Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.
HS-ESS2-4	Use a model to describe how variations in the flow of energy into and out of Earth systems result in changes in climate.

The Design Behind the Scaffold

The MEL scaffold incorporates a series of activities focused around a central socio-scientific topic, such as extreme weather events. The MEL helps students evaluate connections between lines of scientific evidence with alternative and competing explanations (Bailey et al., this issue; Lombardi, 2016). In a series of classroom-based experiments, we have seen meaningful shifts in students' judgments toward a more scientific stance, as well as increased understanding about complex socio-scientific topics (e.g., causes of current climate change and value of wetlands to ecosystem services) when high school students use the MEL scaffolds (Lombardi et al., 2018a,b). The current project, supported by the U.S. National Science Foundation, is trying to optimize the instructional effectiveness of the MEL by promoting increased student agency (i.e., where the student has more autonomy and choice in the learning process). To promote greater agency, we have developed enhanced MEL scaffolds in the current project, which we call the build-a-MEL. Students construct their own diagrammatic scaffolds in the build-a-MEL by selecting four evidence lines from eight choices and two alternative explanatory models from three choices. Students then evaluate the connections between their selected lines of evidence and alternative explanatory models after constructing the diagrams. Finally, they reflect on their reasoning and judgments about these connections in written tasks (see Bailey et al., this issue, for more details).

Extreme Weather Phenomena

The Extreme Weather build-a-MEL presents eight major lines of scientific evidence about various weather-related events, including but not limited to occurrences of record rainfall in the U.S. during the 20th century, increases in North Atlantic tropical storm power intensity since 1970, and record European snowfall over the past decade. Some lines of evidence include multiple weather

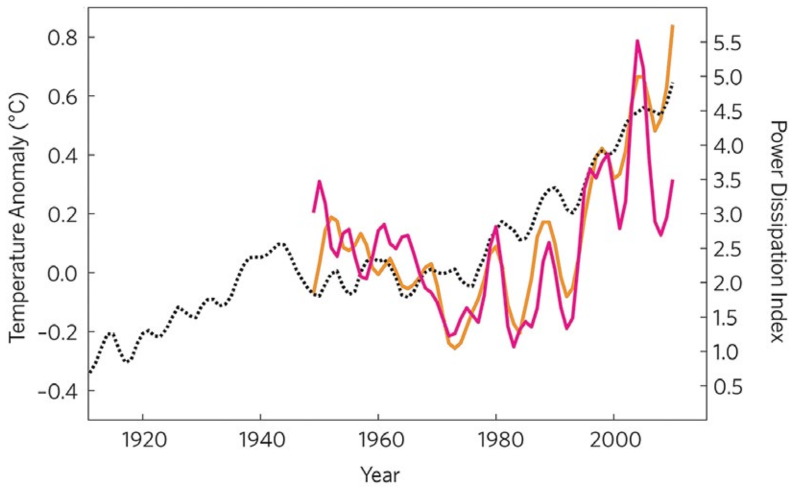

Figure 1. Relations Between Atlantic Tropical Storm Cumulative Annual Intensity (as Power Dissipation Index) and Atlantic Sea-Surface Temperatures

Note. The solid orange line shows ocean temperature anomalies in the Atlantic. Anomalies are things that differ from the "normal" or average conditions. "0" on the left axis represents that average. It is the long-term, global, average, ocean temperature between 1910 and 2010 in the Atlantic. The solid red line shows the power dissipation index (PDI) for tropical cyclones in the Atlantic. The PDI measures the amount of energy a storm releases. The PDI of a storm depends on its strength, how long it lasts, and how often it occurs and reflects the total destructive power in all tropical cyclones for a year. The dotted line represents global average (land and sea) temperatures.

Table 2. Models and Lines of Evidence in the Extreme Weather Build-a-MEL

Model	Statement
Model A [non-scientific consensus]	The number and strength of extreme weather events vary naturally. Human activities release carbon in the atmosphere. Yet, plants and oceans absorb any carbon increases.
Model B [scientific consensus]	Increases in extreme weather events are linked to climate change. Current climate change is mainly caused by human activities, such as fossil fuel use.
Model C [non-scientific consensus]	Over time, increases and decreases in extreme weather events are mainly caused by changes in Earth's orbit around the Sun.
Evidence	**Statement**
Evidence #1	Since 1950, Earth's atmosphere and oceans have changed. The amount of carbon released to the atmosphere has risen. Dissolved carbon in the ocean has also risen. More carbon has increased ocean acidity and coral bleaching.
Evidence #2	From 1910 to 1995, record rainfall events increased across the United States. Over the same time period, there was a sharp increase in the amount of carbon released to the air. Much of this carbon comes from fossil fuel use.
Evidence #3	Ocean sea surface temperatures have increased since about 1970. In the North Atlantic, tropical storm power has also increased over this same time period. A storm's power depends on its strength and how long it lasts.
Evidence #4	Since 2000, there have been more intense, extreme, weather events around the world. Record rainfall fell in Europe. The southeastern United States had the most active month of tornadoes. The decade from 2000 to 2010 was the warmest ever during the past 1000 years.
Evidence #5	Frequency and size of large wildfires have increased in the Western U.S. since 1970. Average spring and summer temperatures have also risen in the Western U.S. during this time.
Evidence #6	In the last 100 years, global temperatures have increased. In that same time period, heavy precipitation events have also increased.
Evidence #7	Arctic Ocean sea ice extent has declined, with the Arctic warming at a pace two to three times the planet's average. Over the last decade, record cold temperatures and snowfall have occurred in Europe and Asia.
Evidence #8	Earth's orbit is elliptical. But, the shape of the ellipse is almost a perfect circle. In the Northern Hemisphere, Earth is slightly closer to the Sun in winter than in summer.

conditions that relate to one specific phenomenon, such as the increase in frequency and size of Western U.S. wildfires since 1970 (see Table 2 for the evidence statements). Such wildfire events are associated with drought, high wind, and/or high temperature events. We synthesized these and other lines of evidence based on results from well-regarded scientific journals (e.g., *The Bulletin of the American Meteorological Society* and *Nature*). For each line of evidence, we developed one-page evidence texts at the high school reading level. These texts often present data in graphical or tabular format (see Figure 1, taken from Evidence #3). We designed the evidence texts to have clear, declarative, and focused statements to facilitate students' comprehension.

Alternative Explanations about the Extreme Weather Phenomenon

The Extreme Weather build-a-MEL also presents students with three alternative explanatory models that relate to these lines of evidence (see Table 2 for the three models). Each explanatory model provides an alternative and conflicting explanation for increases in extreme weather events over the last 50 years. These events include intense hurricanes, heavier rainfall and flooding, dangerous wildfires, and heat waves. One of the three models that students consider is the scientific consensus explanation (i.e., increased occurrences of extreme weather events are caused by human-induced climate change, i.e., the climate crisis; Schiermeier, 2018). The other two models are compelling, but non-scientific explanations, with one saying that (a) the frequency of extreme weather events cannot be linked to human activities because plants and oceans are absorbing carbon emissions, and the other saying that (b) the intensity of extreme weather events ebbs and flows naturally due to long-term changes in Earth's orbit around the Sun.

We encourage teachers not to tell the students which is the scientific consensus when introducing these three alternative explanatory models at the beginning of the instructional activity. Some students may have prior knowledge about one of the alternatives. The purpose of the build-a-MEL activity is to activate this prior knowledge in a way that promotes meaningful knowledge construction. Therefore, telling students at the beginning of the activity what the scientific consensus model is could reduce their willingness to be active agents of their learning. Conversely, we also suggest that at the end of the activities, teachers are very clear about which explanatory model is the scientific consensus. We do caution that, although the scaffold is designed to facilitate students' shifting toward the scientific consensus explanation, other individual factors may prevent students from full acceptance. Therefore, we do not consider the build-a-MEL to be a "silver bullet" lesson, but rather one in a series of activities that teachers could use in a unit covering weather and climate.

Results from Initial Pilot Testing

Our multi-year project has been developing the build-a-MELs using a process of design-based research. Teachers are heavily involved in this process, both in the research design and in the testing of the build-a-MEL materials. During the project's second year, we conducted pilot tests of the freshly developed build-a-MEL materials, including the Extreme Weather build-a-MEL, in several middle and high school classrooms. The pilot tests have yielded some interesting results when comparing the build-a-MEL scaffold (in general) to our previous scaffold version that is pre-constructed for the students. In comparison to this pre-constructed version, the build-a-MEL scaffolds resulted in students being more evaluative with greater shifts in judgments toward thinking that the scientific explanation was more plausible than the alternative. Further, students learned even more about the topic. When specifically comparing the Extreme Weather build-a-MEL to the pre-constructed Climate Change MEL, the pilot tests showed a marked shift in plausibility toward the scientific explanation (~20% greater shift than the pre-constructed Climate Change MEL) and comparable shifts in understanding (~8% increase in knowledge for both the Extreme Weather build-a-MEL and Climate Change MEL). We consider this knowledge increase to be meaningful for classroom instruction because both the MEL and build-a-MEL are relatively short duration activities, taking about 90 minutes of total class time each.

Teachers involved in our pilot test of the Extreme Weather build-a-MEL commented that students enjoyed this activity because they felt it was relevant and they enjoyed debating about the current climate crisis as they worked in collaborative groups. The teachers suggested presenting lines of evidence one piece at a time, and to specifically show evidence text figures (e.g., graphs, charts, pictures) on the projector. The teachers also suggested to remind students to consider the lines of evidence fully as they reflect on the evaluations of the connections between evidence and explanation in the final written task.

Even though we are encouraged by our initial pilot test results, we are revising and further testing the Extreme Weather build-a-MEL, as well as the other three build-a-MELs (see the other articles in this issue). In our continued development process, we consult our project's advisory board, which includes well-respected geoscientists. We also include master teachers who ensure that our materials are classroom-ready. All of the project materials, including assessment rubrics, teachers' guides, and professional development handouts, are freely available on the MEL project website (see Sidebar).

The Model-Evidence Link (MEL) and build-a-MEL activities can be accessed on our project's website, https://serc.carleton.edu/mel/index.html.

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Concluding Thoughts

Challenges facing today's society require citizens to be scientifically literate, which includes knowing the big ideas of science and knowing how scientists construct these big ideas. Extreme weather events are one of the many challenges that our society faces, with such events affecting our local and regional communities. Additionally, the connection between increased occurrence of extreme weather and the human-induced climate crisis has now been well-established via rigorous scientific investigation and research. Thus, to be fully equipped to face future challenges, students need to deepen their climate science literacy by understanding situations where weather and climate events are distinct and directly related. The Extreme Weather build-a-MEL is an instructional scaffold that aims to help students develop scientific literacy in this area by more critically connecting how well lines of evidence support alternative explanations about these phenomena (e.g., increased frequency of severe storms, stronger rainfall episodes, and prolonged periods of drought). In gauging connections between evidence and explanations, and also promoting shifts in judgments toward a more scientific stance, the Extreme Weather build-a-MEL engages students in the process of reasoned evaluation that underpins many scientific practices (Ford, 2015). And by promoting agency to be more scientific in the process of knowledge construction, we hope that the Extreme Weather build-a-MEL will help students, in part, to be better problem solvers in their communities.

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