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2020 Volume IV: Solving Environmental Problems through Engineering

Engineers Wanted: Climate Change Experience Necessary!

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Introduction and Rationale

Henry C. Lea School sits on the corner of 47th and Locust Streets in the West Philadelphia section of the city. Serving close to 600 students, this Kindergarten through Eighth grade school draws about half of the students from the local catchment within walking distance, and the rest from across West Philadelphia and beyond. Lea School has a diverse student body comprised of immigrant students from around the globe and students whose families have lived in the area for generations. Across the city of Philadelphia, gentrification has been taking place as urban flight has made a turn-around and more families seek the benefits of urban living. Lea School is right on the edge of that gentrification, grappling with changing demographics. Across the street from the school is the now-shuttered West Philadelphia High School, an enormous facility that takes up an entire city block. West Philadelphia High School once had over five thousand students enrolled. It is now being converted into loft rentals marketed to a younger generation with rents that are likely beyond the financial means of many local residents.

The 2019-2020 school year presented the eighth grade students at Lea School with a number of serious issues with which to grapple. Even before the emergence of COVID-19, 100% of students attending the school qualified for free lunch and breakfast, and the data kept by the School District of Philadelphia lists 100% of the student body as "economically disadvantaged." Well under half of the students enrolled at the school reached proficiency on any of the three *Pennsylvania State System of Assessment* standardized tests from 2019: science, math or English language arts.[1] As a classroom teacher, I am aware of parents who are working long hours to make ends meet, parents who are incarcerated, students whose parents are likely concerned about deportation, and of course students who have parents living in different households. With the addition of COVID-19 and an intense awakening and debate on race in America (69% of the school self reports as African American),[2] I worry about giving my students one more thing to think about: climate change. But the evidence is clear, if we do not address this issue now, we will have little control over what happens down the road.

Climate change is the undeniable fact of the future, and there are strong arguments to connect the racial inequities to changing weather and changing climate patterns. In a recent editorial in the *Washington Post*, climate scientist and marine biologist Ayana Elizabeth Johnson argues that communities of color should be actively engaged in the climate change fight because statistically, "black people are more concerned about climate change than white people." She makes a stunning plea for white people to immediately address racism so that people of color can turn their actions and protests to the climate crisis rather than having to fight for more basic rights.[3] It is easy to see why black people may be more concerned about climate change than their white counterparts. In the *Fourth National Climate Assessment Report* published by the US Global Change Resource Program, the Summary Report states that people "who are already vulnerable, including lower-income and other marginalized communities, have lower capacity to prepare for and cope with extreme weather and climate-related events and are expected to experience greater impacts."[4] And this also appears to explain why communities predominantly comprised of people of color are being harder hit by COVID-19. Dr. Aaron Bernstein Director of the Harvard C-Change Center for Climate, Health and the Global Environment states that people "with chronic health conditions, lower-income, and communities of color are disproportionately impacted by both COVID-19 and climate change, and pollution is at the heart of both problems…."[5] Figure 1 illustrates some of the likely impacts vulnerable populations may face due to climate change along with some solutions. This graphic seems written for Philadelphia showing rivers, diverse communities, low-income neighborhoods, and urban road congestion all converging to create challenges but also possibly opportunities. (See Figure 1)

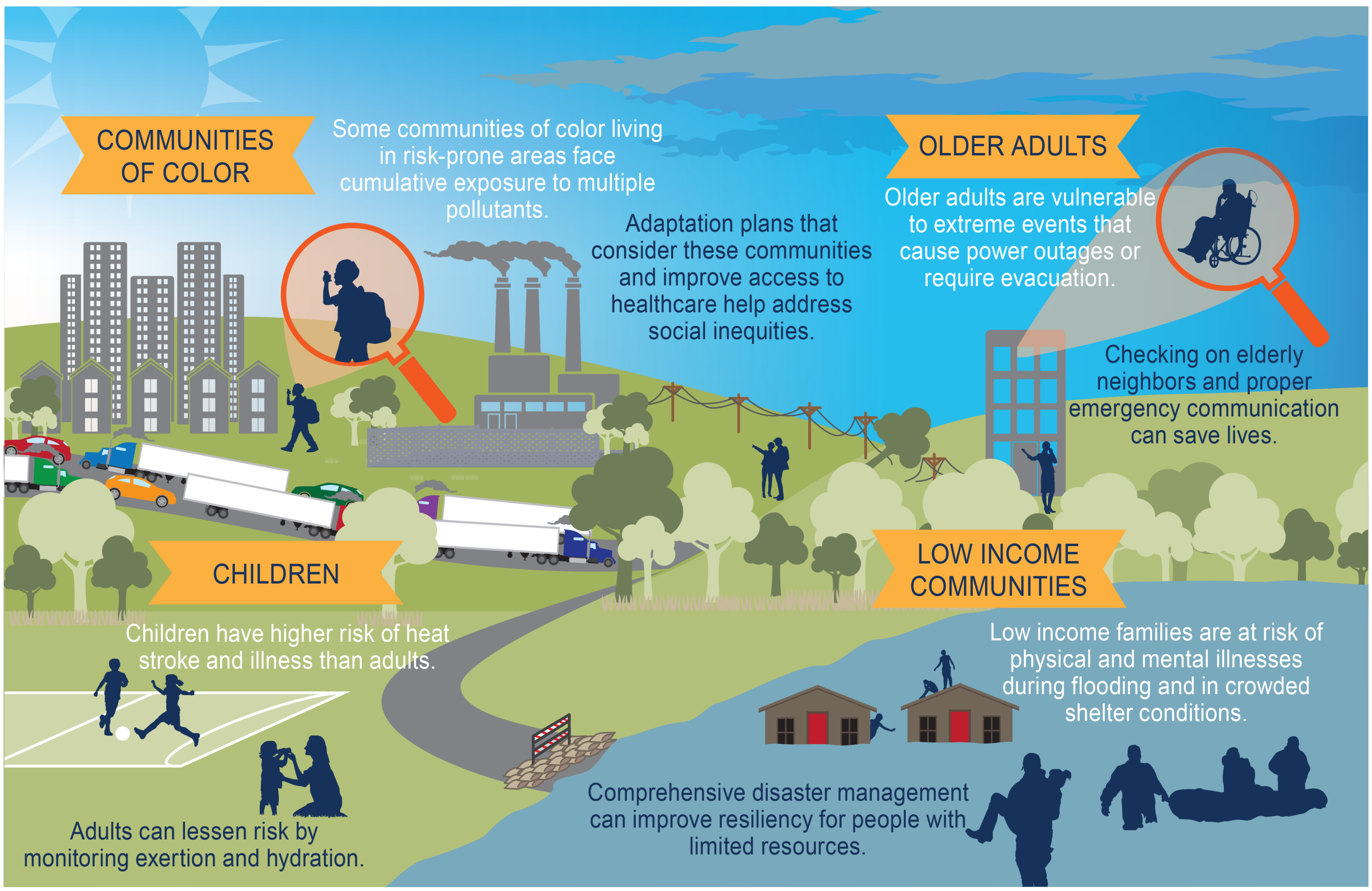

Figure 1. Vulnerable populations are at greater risk for the adverse affects of climate change. Fourth National Climate Assessment.[6]

My 2019 Teachers Institute of Philadelphia Unit: *A Place Based Exploration of Climate Change*, is designed to help urban students find a connection to a sense of place, to understand why climate change is happening, to explore how young people are bringing awareness to the situation, and to illustrate one example of how Philadelphia is dealing with the impacts. This current unit seeks to take over where that one leaves off, but will also exist as a stand-alone unit for teachers who choose. Embedded within a project based approach, students will begin with several basic lessons on the causes of climate change, including the connection between fossil fuels and climate change and the associated changes in human behavior that are surely going to need to happen. Students will also explore the local situation with regard to climate change. Middle school students need to connect to what is in front of them, and my students know *city*. They will then explore a variety of possible engineering solutions to adapt a building to climate change, ones which might not be immediately apparent and which will move beyond individual responsibility to lower fossil fuel consumption and mitigate its effects.

For this unit, students will be tasked with collaborating with peers in a project-based approach to develop engineered models that respond to climate change. The project will seek to answer one key question or problem statement: How can we retrofit our school building to adapt to and mitigate climate change. Here, I seek to ask a central question that is locally based, relevant, age-appropriate and attainable. And one that gives hope to children that the choices they make can have an impact for their community. Embedded in these activities will be explorations of different types of engineering choices to help students grasp complex concepts in science and design, and also to present career choices. Students will engage in dialogue about whether solutions are addressing the causes of climate change or addressing the visible effects. They will then present their chosen engineered designs, and will be asked to convince an "investor" why there is a need for an immediate investment in this solution. Use of online platforms will be included in the unit, as students may need to complete virtual school in the coming years.

As a likely introductory unit on climate change, the goal for this unit will be multifaceted. Students will finish the unit with a basic understanding of why and how climate change is occurring. They will explore the impacts climate change is likely to have locally, giving them a sense of the future of their own surrounds. Students will also look at some of the underlying universal truths of climate change: that we can make an impact by lowering our carbon footprint and also need to prepare for the inevitability of change. In this particular unit we will focus on tangible design and engineering solutions that will be of benefit. Students will also have the chance to work together collaboratively using a project based approach and will present their choices to peers and staff to build communication skills and confidence. All standards to be addressed in this unit were chosen from Pennsylvania Department of Education standards.

The History of Climate Change

The causes of climate change are no longer of any debate worldwide. The burning of fossil fuels is releasing too much carbon dioxide (and other greenhouse gases) into the atmosphere and is raising the average global temperature. Methane production from animal farming is also a major producer of greenhouse gases with the deforestation required to grow livestock contributing to a negative feedback loop. (A negative feedback loop is like a problem compounded by itself: greenhouse gases are on the rise from cattle production, but now you have cut down the trees that help use atmospheric carbon dioxide.)[7] How did we get to this point? In her book *The Story of More*, geobiologist and author Hope Jahren, lays out a clear pathway from population growth and increased consumption to climate change. Born in 1969, she chronicles the changes in her own lifetime to illustrate the point. In the past fifty years, farm acreage has increased very little worldwide (only about 10%), but production of grains has almost tripled.[8] To support that growth is a worldwide tripling of the use of fertilizers, doubling of irrigation, and a tripling in the manufacture of pesticides to keep out the undesirables.[9]

Jahren tells a similar story of meat and sugar production tripling as well since her birth in 1969.[10] These aren't the only topics she covers. From travel to packaging to food waste, she argues, everything is MORE. More requires *more* of everything: more fuel to produce and transport products, more refrigeration, more electricity needed, more packaging. These resources are obviously distributed unequally throughout the planet with widely varying standards of living contributing in differing amounts to global warming. Nations with a higher standard of living are often the ones contributing the most to climate change. The United Nations Development Programme *Human Development Report 2019* reports that the richest countries contribute the greatest per capita emissions of carbon dioxide which in turn contribute the most to climate change.[11]

With world population doubling during the same time frame (from 3.5 billion to 7 billion), increased production and consumption comes at a cost: Global Warming (or Global Weirding as some people call it) now referred to more widely as climate change. The *Intergovernmental Panel on Climate Change (IPCC)* is the United Nations' "body for assessing the science related to climate change." Since 1988, IPCC provides "regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation to chart the increase in temperature across the globe and explain its effects."[12] The current report cycle, called the *Sixth Assessment Report* is based on the idea that if we find ways to hold the temperature increase to an average of 1.5 degrees Celsius compared to pre-industrial levels, we will see consequences that we can predict. Choosing an appropriate course of mitigation or adaptation will be easier with those prediction models. With a 2 degree Celsius increase we will see consequences that will be much harder to control and predict. The scale and severity will simply be too large. Keeping in mind that global average temperatures have already risen about one degree Celsius since 1900, we are talking about increments of half-degrees in Celsius temperature (from 1.5 to 2 degrees) making all the difference in what kind of future our children and grand children will have. But even holding the temperature increases to 1.5 degrees Celsius seems unlikely. The IPCC report states: "By 2030, we need to decrease CO_2 emissions by 45% which would reach net zero emissions at 2050 just to maintain 1.5 degrees C."[13]

Climate Change Basics: The science behind rising temperatures.

The Earth is wrapped in a blanket of fleecy warmth made of greenhouse gases. I remember watching Al Gore's documentary film an *Inconvenient Truth* almost twenty years ago, and being shocked when he said "that's a good thing." I thought we were fighting greenhouse gases! It turns out greenhouse gases fundamentally make the Earth habitable. The law of conservation of energy states that any energy put into a system has to be equal to the output of energy. If the Earth were merely to receive the energy of the sun, absorbing some of it and radiating the rest of it back into space, *without* its atmospheric greenhouse blanket, it would be a *very* cold place, likely uninhabitable by life as we know it. Thinking about how I might teach this to middle school students, the following analogy might work. My tea is hot because I heated the water on the stove (energy in) to pour into my mug. If I let it sit on the counter long enough, all the heat will dissipate (energy out), and I will be disappointed with a cold mug of tea. I need something to hold the heat in. If I put my hot tea into a thermos (like wrapping it in a blanket), it will stay warm quite a long time by trapping the heat. Insulation is needed, and a thermos provides that. Greenhouse gases in our atmosphere provide insulation for the Earth. But too much greenhouse gas is like layering too many blankets! Figure 2 shows the increase in annual temperatures from 1880 to the present. Note that the dates directly correspond to the increase in fossil fuel consumption and combustion post Industrial Revolution. (See Figure 2) The science behind solar radiation and greenhouse gases is complicated, but it may be enough just to begin with the greenhouse gas blanket concept for middle school age students. Gases actually hold warmth and radiate it back to Earth, with different gases having different warming potential. The Earth's atmosphere and surface also reflects some of the sun's rays, a term which scientists call *albedo.* That reflectivity also helps regulate temperature on the planet. With darker surfaces having a low albedo, absorbing more of the sun's energy, and lighter surfaces having a higher albedo reflecting more energy.[14]

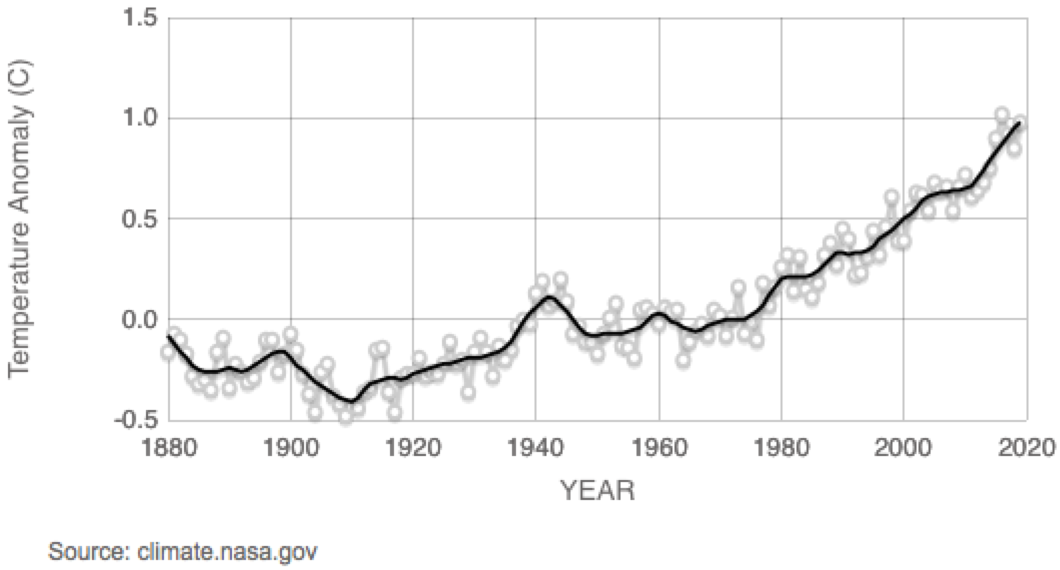

Figure 2. Warming trends attributed to climate change. Climate.nasa.gov[15]

The Greenhouse Gases: More than just CO_2

Greenhouse gases are comprised of many different gas compounds from a myriad of sources. Some of these compounds occur naturally but have been on a dramatic quantity increase since the start of the Industrial age around 1850. (See Figure 3) There is an accounting for the potential warming effect of each gas called the Global Warming Potential that combines the known heat trapping qualities of a gas with the life span of the gas. Carbon dioxide is defined as a "1" as it is the base against which all other gases are compared.[16]

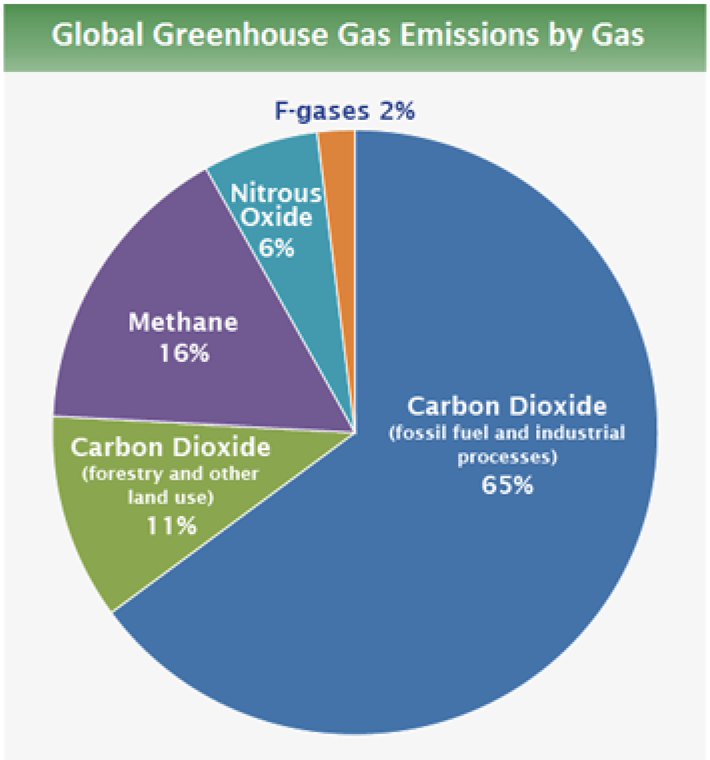

Figure 3. Percent breakdown of the greenhouse gases globally including some of the attributed sources. epa.gov[17]

Methane Gas (CH_4)

Methane gas is made of carbon bonded with hydrogen mainly released from animal waste. Manure and livestock production are the largest sources in the United States. Enteric Fermentation from ruminants is a large contributor to this. (Enteric fermentation is a scientific way to describe that cows pass gas.) Methane represents a slim 16% of the greenhouse gas blanket globally, but it's a very warm part. The Environmental Protection Agency states that while methane has a shorter life span in the atmosphere than carbon dioxide, it is 25 times more efficient at trapping heat in the Earth's atmosphere.[18]

Nitrous Oxide (N_2O)

Nitrous Oxide represents a small portion of the greenhouse gas blanket. In the United States, most of it is contributed through the application of nitrogen-based fertilizers in agriculture, but it is also a by-product of fuel combustion.[19]

Carbon Dioxide (CO_2)

CO_2 represents the largest piece of the greenhouse pie, and the one we hear about the most. Carbon dioxide is a natural byproduct of respiration in many organisms, but the recent dramatic increase correlates directly to an increase in fossil fuel combustion and consumption. While not as efficient at trapping heat as methane, carbon dioxide is the largest single contributor to the GHG mixture. Carbon dioxide could also be part of a negative feedback loop: the more we cut down forests to create room for human development and agriculture, the fewer trees and plants we have to help utilize the gas.[20] Carbon dioxide is measured in parts per million (ppm). Based on ice core samples, the CO_2 level before the Industrial age was under 300 ppm. Figure 4 shows the relative stability of carbon dioxide concentrations in the atmosphere until quite recently, when levels began topping 400 ppm. (See Figure 4)

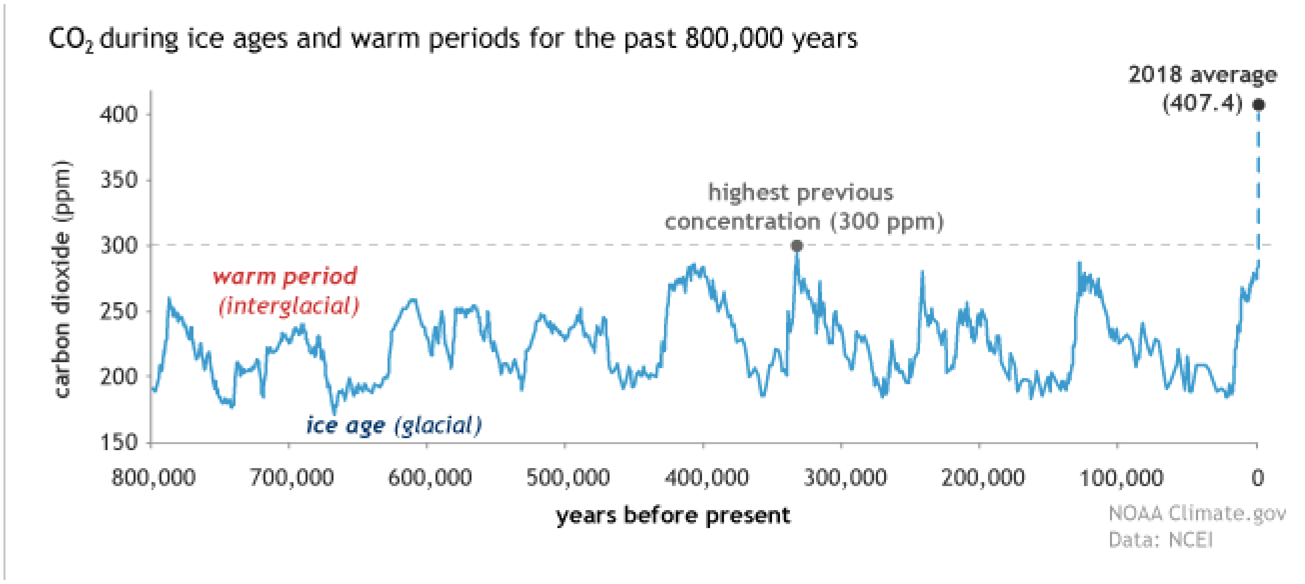

Figure 4. National Oceanic and Atmospheric Administration graph charting historic carbon dioxide levels (ppm). Noaa.gov[21]

Additional Greenhouse Gases

F-Gases include a class of compounds with fluorine that are used in industrial processes and refrigeration. While not included in this graph, water vapor (H_2O) and ozone (O_3) are also classified as greenhouse gases though they are not considered to be major contributors to the problem of climate change as their concentrations are not significantly increasing due to anthropogenic activity.[22]

Climate Change: What happens as global temperatures rise.

For years, it was called Global Warming, and the average temperatures recorded across the globe *have* increased. But this does not play out the same in every community, in every ecosystem. Warming water and warming land result in different weather patterns, different microclimates, and changing habitats for local organisms. It makes sense that the term has morphed to Climate Change. It is important to sort out the difference between weather and climate for students, as they can be confusing terms. *Weather* refers to a meteorological event that occurs at a specific time and place. *Climate* describes what the weather is like over an extended period of time in a specific region. This subject heading on the National Oceanic and Atmospheric Administration website sums it up nicely: “What’s the Difference Between Weather and Climate? Climate is what you expect, weather is what you get.”[23] Both are changing.

The Climate is changing, and so is the weather.

A recent report from IPCC, *the Summary Report for Policymakers on Climate Change and Land* focuses on slow climate change processes ranging from increased desertification in Sub Saharan Africa, parts of East and Central Asia and Australia to contraction of polar climate zones with accompanying sea level rise and coastal erosion impacting other areas.[24] The *Fourth Assessment Report* lists impacts for individual regions in the United States. The Southwestern part of the United States has seen an increase in wild fires at the same time it is facing water shortages, both due to drought and exacerbated by increased development across the region.[25] The Northeastern part of the United States is seeing increased flooding. These floods are caused by intense storms. The rapid rate of precipitation can cause stream, river and coastal flooding contributing to temporary or permanent displacement.[26] While drought is also listed as a potential consequence of climate change for the Northeast, it is the heavy rain events that will likely be the most devastating.

The organization *World Weather Attribution* publishes assessments of weather events from across the globe determining the probability that the event had an increased likelihood or severity due to climate change. The goal of the organization is to identify “a human fingerprint on individual extreme weather events” or “probabilistic extreme event attribution.”[27] Wildfires in Australia are normal occurrences, but was the 2019 season worse due to climate change? The assessment from WWA was yes.[28] A glance at the WWA website shows that they categorize weather events not just by heat waves and wildfires, but also by drought, extreme rainfall, cold spells, and storms, including hail, snow, thunder, etc. In 2019 the following occurred: extensive Australian bushfires, unusual southern European cold snaps, unusual northern European heat waves. Texas received extreme rainfall. These all produced assessments from WWA that climate change had definitely increased the likelihood and the intensity of the event.[29] The climate changes in small increments, weather events capture our attention for their severity and destruction.

Climate Change: What are we going to do?

Floods, erosion, wildfires, sea level rise, desertification, oddball storms. How is a person supposed to grow crops, sustain livelihood, keep safe in her home? What will these changes mean for the 2 (or more) billion people who live in coastal towns and whose food and livelihoods depend on the sea? What will this mean for urban dwellers who are likely to see more days with hot weather and experience adverse health effects? With both weather and climate changing, humans are facing choices at personal, local, national and international levels: prevent further warming and mitigate damage or adapt our farming, housing, transportation, our whole towns and cities to the coming reality. There is the real possibility that thousands of people will become climate migrants having to move when their city becomes uninhabitable or farming becomes impossible. In all likelihood, given the IPCCs prediction that we will not be able to hold warming to 1.5 degrees Celsius, we will need to both mitigation AND adaptation.

Mitigation or Adaptation

Mitigation for climate change involves one basic key idea: slow down the rate of average global temperature increase by reducing the amount of greenhouse gases in the atmosphere. One key idea, but no easy solution. Cutting carbon emissions is likely to be a multi-point effort: lower fossil fuel consumption, increase renewable sources, reform agricultural practices. Another mitigation option is to somehow capture the carbon we create. Carbon sequestration is the process of capturing carbon so that it cannot become a greenhouse gas. Carbon would have to be "sunk" or sequestered somewhere so that it would not release back into the atmosphere over short time spans. If fossil fuels were buried deep beneath the surface of the Earth or the ocean, then that is potentially a good place to put it back.

Adaptation involves recognizing the coming effects of climate change and engineering solutions to solve the problem. Addressing sea level rise? Maybe shore houses need to be put on stilts, sea walls built and sand dunes and wetlands strengthened. Addressing rising temperatures? Sunlight can be reflected with light colors. Maybe roofs can be painted white or silver? Some people even suggest sending large solar reflectors to space to reflect sunlight.

Mitigation and adaptation to climate change are vast, vast topics. You could read endlessly online about it. Nobody has an easy or one size fits all solution, and every locality demands a different response. It is beyond the purview of this paper to discuss more than a fraction of those solutions, and they will vary quite widely according to geography, population and existing climate. Teachers should check local municipal websites and utilities for local initiatives surrounding climate change. Ideas and conditions change constantly. For that purpose, I have also tried to use sources as current as possible. The basic science and concerns around climate change are stable, but the solutions are evolving and endless. In addition, while I have based this unit on mitigation and adaptations solutions for Philadelphia, it should be easily implemented in other parts of the country. Local municipalities, environmental organizations and museum websites often have information regarding local impacts and solutions to climate change.

Philadelphia: One city's likely scenario in the coming climate crisis.

When you type Philadelphia and Climate Change into your search engine, the first thing that comes up is a phila.gov (City of Philadelphia) link with the word *sustainable*. Click on that link and it ports you directly to the Philadelphia Water Department website and two key words stand out: warmer and wetter.[30] Philadelphia is hot in the summer. Days in the 90s are the norm, sometimes coming as early as May and lasting well into September. Philadelphia averages about 3 inches of rain per month year round, but those storms often come in intense outbursts. With a city of impervious surfaces, stormwater runoff floods our sewer systems creating the dreaded combined sewer overflow. Combined sewer overflows dump untreated wastewater from homes mixed with water from the streets into our local waterways. With wetter weather, combined sewer overflows may increase, though Philadelphia does have an official mitigation plan for that.

Philadelphia relies on The Schuylkill River and the Delaware River for drinking water. Saltwater intrusion into the drinking water treatment plants is on the list of possibilities for troubles that the city could face. Rising sea level could mean that the salt water would travel further up the estuary than in the past, getting into the intakes for drinking water and making filtration difficult or impossible. Philadelphia has air quality issues as well, which impact city dwellers adversely. The city is rated as having one of the worst air quality ratings in the United States. The *Asthma and Allergy Council* ranked Philadelphia in the top 3 worst cities: nearly one in ten people suffer from asthma.[31] Increasing temperatures cause increases in ground level ozone irritating the lungs of asthma sufferers. In urban environments such as Philadelphia, that translates to thousands of people who have asthma contending with increased risk.[32] Keeping temperatures cooler could help reduce that risk.

Unit Planning for Middle School Students Studying Climate Change

While Hope Jahren's *Story of More* is a wonderful book, it is hard to make an argument to children that they should want less. It is an especially tough argument for students who may literally not have enough to begin with: food, space, opportunity. A basic understanding of the science of climate change and the inequities associated with the effects are critical to helping students unpack current debates and political and future realities for them. This generation has grown up *in* climate change, so they might not see the problem. They have nothing to compare it to. But they are the ones to receive the problem, and they are the ones to be impacted at the greatest level. Climate change has to connect to them, and they have to connect to it.

Pedagogy and Teaching Strategies for this Unit.

Project Based Learning

Project Based Learning is gaining in popularity across the United States as a means to engage students in critical thinking using multi disciplinary projects, and climate change is definitely a multi-disciplinary problem. One of the key mandates of the Common Core initiative is to have students think more deeply about a problem and do less rote memorization and fact based learning. *Engineers Wanted! Climate Change Experience Required* is a project that seeks to marry the process skills needed to collaborate, design and model a small-scale solution to climate change while also developing collaboration skills, communication, reading, writing and deep thinking to solve a problem. For this unit, I am using guidance from the *Buck Institute for Education's* publication, *PBL for 21st Century Success: Teaching Critical Thinking, Collaboration, Communication, and Creativity* from the Project Based Learning Toolkit Series. The book maps out a series of steps to engage groups of students in these types of projects.

Projects are based on a central question that elicits complex and varied answers and solutions. Some examples in the book include: *How should the Supreme Court rule on the case of _______? What is the best way to keep pollutants from our school parking lot out of the creek at our neighborhood park? How can we design emergency housing for disaster victims so that it is inexpensive, easy to transport, and quick to install?*[33] You can see that these are questions with no easy one-statement answers. To attempt to answer these requires collaboration, research, and thinking about the effect of each decision. Teachers generally choose the central question. The key question for this unit will be: *How can we retrofit our school to mitigate and adapt to climate change?* It was important to me to steer clear of designing a building from the ground up. I wanted students to look at existing choices and structures to see what is possible to change and what will not be possible to change. It makes the struggle to adapt more constrained, but perhaps more realistic. We are going to have to work with the houses and schools we have in the future unable to always get new. I chose the school as a neutral locale that all students have a familiarity with, of course, this could be adapted to work for other buildings.

Students next enter the *Launch* phase of the project where they brainstorm the key question and then determine what they are going to need to know to answer this question. During this phase students are placed in appropriate groups and complete a warm up activity that helps them connect with each other as learners and classmates. Guidelines for appropriate interactions are also established. Students then move into *Building Knowledge Understanding and Skills* where they work with each other and their teacher to gather the information needed to come to some kind of response or answer. This may involve online research, teacher led lessons, videos, reading, experiments. This will be an important period during which appropriate math and science skills will be developed and strengthened. For this unit, I intend to look in depth at graphs relating to climate change, determine the causes of climate change, and explore the inequities that will result from climate change using data and statistics. Students will also determine how their own city will be impacted.

During developing and *Revising Ideas and Products* students generate designs, build prototypes, construct arguments and receive critical feedback from other teams and from adults. Students should already be familiar with the rubric for scoring which should also be shared with parents at the beginning of the project. Finally, students will present their “products” or “answers” to the original question. This could take the form of a presentation, or a model or a video. Students will go through several iterations of their school retrofit with teacher and peer feedback at each level to refine their understandings and choices. In the final phase of Project Based Learning *Presenting Products and Answers to Driving Questions* students will share their collaborative designs and justify their choices. How do the choices they made about redesigning the school building help solve or adapt to climate change? Students will need to articulate in writing or orally on each key point. Students are then scored on a rubric using peer and teacher feedback.

Direct Instruction/Teacher Presentations

To support Project Based Learning, teachers will need to supplement student research with specific content. With online learning a distinct possibility for the near AND distant future, it is important to have well crafted mechanisms for presentation. While presentations such as these are often teacher led, they can be an important resource for students to refer to on an ongoing basis. For this unit students will need some basic information on solar radiation, greenhouse gases, carbon footprints, and renewable energy sources.

Digital Learning

In addition to PowerPoint presentations, students may need to collaborate online either by researching and collecting information or by using small online “rooms” to meet with teacher supervision in order to collaborate on design and refine arguments they will need to make for presentation. A critical aspect of the project is for students to discuss their ideas about climate change solutions for the school and work out an agreement on what that will look like. Students will also need to collaborate on a shared platform for sketching their engineered designs should remote learning be essential. In the absence of in person learning, students can use chat rooms or meets to discuss, with teachers dropping in to check on progress.

Laboratory Experiments

Using the scientific method, students will conduct several controlled experiences with independent and dependent variables. Relevant to this unit, students will conduct labs on the effect of color on light/heat absorption and on the properties of insulation. Students will need some basic lab equipment for these labs (beakers, thermometers, insulated cups) and will need to write a lab report with components of the scientific method to reinforce understanding of science lab procedures.

Design Challenge

For this project, students will be asked to create a model of their school with mitigations and adaptations for climate change evident. Creation of a tangible model is age appropriate for middle school students as they still very much need to *do* and create, enhancing student engagement. Students will need materials for sketching a prototype, which includes multiple iterations and feedback and for the final product that may include but are not limited to: paper, cardboard, glue, paint, scissors, markers, foil, note cards, colored paper. Teacher may want to consider the cost and accessibility of materials especially if students are at home with school closures.

Presentations

Students can present their designs and justifications for retrofit design choices to other peer groups, to other students in the building, to teachers and administrators. This strategy allows students to strengthen their communication skills and refine their reasons for the choices they made in their school design. Students will be required to articulate the choices they made regarding climate change. For example: “We chose to paint the roof white to reflect the heat from the sun and lower the temperature of the building so that not as much air conditioning needs to be used in the summer. This will also lower the school’s fossil fuel consumption.”

Classroom Management

Teacher must establish a clear set of behavioral expectations during this unit. How are students going to work together? How will they respectfully communicate? What happens if they disagree or run into barriers? How do they ask for help? PBL for 21st Century Success has excellent suggestions for how to foster a healthy classroom environment.

Rubric Assessment

Students and parents will receive a rubric at the beginning of the unit so that they fully understand what the expectations are and how they will be graded. Rubrics have levels of accomplishment and can assess engagement, effort, content and presentation skills. Rubric assessment will help students hone in on the justification they need for each retrofit choice they make for their model.

Lesson Activities

Lesson Activity 1: Launch

Students are assigned to groups at the teacher’s discretion and stay with these groups for the duration of the project. Careful consideration should be given to the composition of the groups with respect to English language status, special education status, behavior, and personality. Groups of three to five will work best. Using the Project Based Learning model, present the following problem statement. *How can we retrofit our school to better adapt to and mitigate climate change? Design a model of the school to show your choices.* Give students the written prompt on paper and in large print on the board. Have students brainstorm the problem statement writing down what they will need to ask, answer and know to be able to complete this assignment. Here are some guiding questions for teachers: What do we understand about this statement? What do we need to find out more about through research? What does “design a model” mean? What is a retrofit? What is the difference between adaptation and mitigation? What do we need to know to be able to complete this task? Who needs this and why? Once students have had a chance to write their questions regarding this prompt, have each student from a group read one of their questions while the teacher records responses on a piece of chart paper. Collect student responses to see if all questions have been reported. Potential student questions generated will likely fall into several categories: questions about climate change, questions about how Philadelphia will specifically be impacted by climate change, questions about the school building, questions about the specifics of the project: materials, time frames, grading, presentations, questions about mitigation and adaptation. In a learning model such as this, there is room for students to explore at different levels. It is possible that some students will ask other questions about renewable energy, about building design, about how to construct models. Subsequent lessons are designed to help students find answers to these questions and also to give some important information about specifics relating to the project. For this project it would be wonderful to have students create a scale model, it depends on the comfort level of the teacher and students with the extra work involved.

Lesson Activity 2: Building Knowledge, Understanding and Skills

During this phase of the Project Based Learning model, the teacher starts by providing direct instruction on key scientific concepts on global warming, reviewing solar radiation and the greenhouse effect. The teacher then presents information on fossil fuels and how the consumption and combustion of fossil fuels is contributing to climate change. Teachers should point out that weather and climate are two separate but interrelated ideas. Videos, lectures and slide show demonstrations, information that are presented can be referred back to for facts as students make decisions about design choices. This is aimed at helping students understand climate change sufficiently to be able to answer questions later about mitigation and adaptation. Using graphs from Climate.gov have students examine graphs. Climate.gov has an exceptional set of live/animated graphs if more complex graphs are desired. Have students document what they notice and what they wonder about each graph. They will work within their groups and must analyze and report back to the other groups. Student groups then draw a conclusion based on what they have learned in one statement with an argument to back it up. Students can then summarize their key findings in writing. Teacher will give the following writing prompt: What have we learned today about climate change? How will climate change impact me, my family, and my community? Teacher records conclusions on chart paper, looking for accuracy and correcting as she goes. Students will have access to this information posted in the classroom or on a shared digital document.

The following two science investigations will also strengthen understanding regarding heat reflection, absorption, and insulation necessary not only to understand climate change but also to consider the response to it. During the first lab, have students compare the temperature under two sheets of construction paper that have been placed in direct sunlight, one black and one white. Using a thermometer, have students record the temperature at regular intervals. Students will notice that the temperature increases more quickly and stays warmer under darker colors. They can use this information to help inform the design changes for the school model, asking when a darker color would be helpful, and when a lighter color might be helpful. For the second science investigation, students will use an insulated cup or thermos to test the rate at which frozen water warms and hot water cools when compared against the same samples placed in cups with no insulation. This too will help students understand why insulation is a helpful tool in heating and cooling buildings, thereby lowering fossil fuel consumption and the school's carbon footprint. This information will also be used for student school retrofit design choices. Finally, students should be familiar with the school and its systems, examining the physical facility for heating, air conditioning, ventilation, water, windows, landscaping, etc. Tours of the school to examine these systems may help students see the building in a new way, as a facility to be managed. At teacher and principal discretion, students should interview building engineers, maintenance facility managers, custodial staff, and other key facility managers to determine how the building is heated and cooled, existing problems in the building, heating bills, water issues, shade structures, and trees and plant life, shades, windows, etc. Students will need to weigh their retrofit choices carefully. Enhancing insulation may reduce airflow, which may in turn require increased ventilation. Planting trees for shade may take up valuable play space. This is an opportunity for students to think through their decisions and recognize that each choice comes with a consequence. Teachers will want to be familiar with the specific issues of their locale regarding climate change. As Philadelphia will face more intense storms and flooding is an issue, students will want to look at the way water is managed in and around the building. As students progress in their knowledge of climate change, teachers can foster conversations about what students have learned and how to connect this to the assignment.

Lesson Activity 3: Developing and Revising Ideas and Products and Presenting

Students summarize what they have learned so far about climate change and how it will impact their school through a short written assignment assigned by the teacher. Students should also write about what considerations they need to keep in place regarding their specific school building. The teacher will read each essay and make comments or ask questions to get students to think more deeply. Teacher will meet with each group to discuss their plans for a retrofit, how students will work together and clarify any misconceptions. Students bring their essays to their group with teacher comments and suggestions. In their groups, students are ready to discuss what they found out and what they believe they need to keep in mind about the school. They can begin designing retrofit solutions for the school building and talk about how they are going to accomplish showing them on the model. Student groups then work to make a first draft of their design on paper. Through a series of iterations, which may take a few weeks, the teacher requires more and more refinement by asking student to clarify their sketches, determine what materials students will need for construction of the model. This will be a good point to contact parents and inform them of their student's progress and goals. Seeking feedback from other teachers, building engineer, principal, availability, other peers as part of this iterative process will be beneficial to each group.

For the final, three-dimensional model, encourage students to use recycled or discarded materials, not purchase materials. The final model allows students to add creativity, color, style and design to their presentations and to fully formulate justifications for each choice they have made. Students should have a format for writing or displaying each retrofit choice they have made. Students can use a carousel method for showing off their final products with half of a team staying behind to show their work and the other half listening to presentations then switching groups. Teacher will score final projects using a rubric and may want to organize a show (could be a photographic show) for other building participants.

Bibliography

American Chemical Society, n.d, Accessed July 2020. https://www.acs.org/content/acs/en/climatescience/energybalance/predictedplanetarytemperatures.html.This site maintained by the American Chemical Society has resources for teachers and students on energy transfer from the sun, greenhouse gases, and climate change. It is very instructive on the science behind climate change, good for the basic facts!

Asthma and Allergy Foundation of America. "Asthma Capitals 2019" Accessed July 15, 2020.

https://www.aafa.org/asthma-capitals-top-100-cities-ranking/

Asthma and Allergy Foundation of America. “Climate and Health” Accessed July 29, 2020. https://www.aafa.org/climate-and-health/. Asthma and Allergy Foundation of America provides information for allergy and asthma sufferers and also assesses the impact of air pollution and climate change on our ability to breathe.

Bernstein, Aaron. “A Conversation on COVID-19 with Dr. Aaron Bernstein, Director of Harvard Chan C-CHANGE” Harvard University C-Change Center School of Public Health, n.d. “Coronavirus, Climate Change, and the Environment” Accessed June 2020. https://www.hsph.harvard.edu/c-change/subtopics/coronavirus-and climate change/. Harvard University’s TH Chan School of Public Health’s C-Change Center for Climate Health and the Global Environment publishes information that connects climate change to health impacts and has information about how COVID-19 and other infectious diseases are spreading more rapidly and causing more illness and greater mortality due to climate change.

Boss, Suzie, Larmer, John, and John Mergendoller PhD, 2018. PBL for 21st Century Success: Teaching Critical Thinking, Collaboration, Communication, and Creativity, Buck Institute of Education. This book is designed to be a practical guide for middle and high school teachers to implement project-based learning (PBL) including sample projects, rubrics and the integration of technology.

City of Philadelphia, n.d. “Climate Change Adaptation”Accessed July 15, 2020. https://www.phila.gov/water/sustainability/Pages/ClimateChange.aspx. The City of Philadelphia, well aware that climate change is happening, has produced this comprehensive report looking at the myriad of impacts that the city is likely to face.

Fourth National Assessment Summary Findings. United States Global Change Research Program, Accessed July 2020. https://nca2018.globalchange.gov. The Global Change Research Act of 1990 requires that the US Global Change Research Program present a report to Congress and the President every four years with updates on climate. The National Oceanic and Atmospheric Agency (NOAA) serves as the lead agency for compiling this report that details the effects of climate change.

Fourth National Assessment Chapter 18: Northeast. United States Global Change Research Program, Accessed July 2020. https://nca2018.globalchange.gov/chapter/18/

Global Greenhouse Gas Emissions Data. Environmental Protection Agency. Accessed July 2020. https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data. The Environmental Protection Agency site has a breakdown of different types of greenhouse gases, their sources and their relative strengths in impacting global warming.

Human Development Report 2019. United Nations Development Programme, Accessed July 2020. http://hdr.undp.org/sites/default/files/hdr2019.pdf

Intergovernmental Panel on Climate Change, n.d. Accessed June 2020. https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_summary-for-policymakers.pdf. https://www.ipcc.ch/report/ar5/wg3/. This is the Fifth Assessment Report for Climate Change for IPCC (2014). Climate Change Report: Mitigation of Climate Change. This is a technical document for Summary for Policymakers that outlines energy use changes that will assist in mitigating climate change. Also included here is a link to Figure 3 as reprinted by epa.gov.

Jahren, Hope. Story of More: How We Got to Climate Change and Where We Go from Here Penguin Random House, 2020. Jahren is a well-respected geobiologist and geochemist currently at the University of Oslo. She has compiled extensive statistical data to strengthen the argument that our need for MORE of everything (travel, food, electricity, plastics, sugar) has led to the current climate crisis and the only way forward is to want less and more equitably distribute what we already have.

Johnson, Ayana Elizabeth, "I'm a Black Climate Scientist" Washington Post, June 3, 2020. https://www.washingtonpost.com/outlook/2020/06/03/im-black-climate-scientist-racism-derails-our-efforts-save-planet/. This article by marine biologist and climate scientist Ayana Elizabeth Johnson addresses the need to confront race issues in America so that all of us can turn our thoughts towards mitigating and adapting to climate change. The author also helps make connections between racial inequities, vulnerable populations and climate change consequences.

Lindsey, Rebecca "Climate Change: Atmospheric Carbon Dioxide" National Oceanic and Atmospheric Administration. Climate.gov. February 20, 2020. https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide. The National Oceanic and Atmospheric Administration climate.gov publishes a stunning array of graphs and data regarding climate change. Some of these are interactive graphs allowing students to set different parameters and see the effect. Others are fixed graphs suitable for printing and sharing with students.

NASA Global Climate Change: NASA's Goddard Institute for Space Studies (GISS). Accessed July 15, 2020. "Global Temperature" https://climate.nasa.gov/vital-signs/global-temperature/

National Resources Defense Council. https://www.nrdc.org/stories/philadelphia-climate-change-can-take-your-breath-away. National Resource Defense Council article from 2017 on projections for the issues Philadelphia will face due to climate change.

"Overview of Greenhouse Gases" Environmental Protection Agency. Accessed July 2020. https://www.epa.gov/ghgemissions/overview-greenhouse-gases

Pennsylvania Department of Education, n.d. Accessed June 2020. https://www.stateboard.education.pa.gov/Documents/Regulations%20and%20Statements/State%20Academic%20Standards/Academic%20Standards%20for%20Environment%20and%20Ecology.pdf. List of Pennsylvania State Standards for the Environment and Ecology across grade bands.

School District of Philadelphia. philasd.org. Accessed June 2020. https://dashboards.philasd.org/extensions/philadelphia/index.html#/. This portion of the School District of Philadelphia's website allows viewers to see enrollment and demographic data for a specific school as well as overall testing scores, suspensions, and attendance data.

Sixth Assessment Report. Intergovernmental Panel on Climate Change, Accessed June and July 2020. https://www.ipcc.ch. IPCC stands for The Intergovernmental Panel on Climate Change (IPCC), which is the United Nations body for assessing the science related to climate change. The Sixth Assessment Report is being written now to be in progress now for full release by 2022. According to the website: Since 1988, the IPCC has had five assessment cycles and delivered five Assessment Reports, the most comprehensive scientific reports about climate change produced worldwide.

"Understanding Global Warming Potentials" Environmental Protection Agency, Accessed July 2020.

https://www.epa.gov/ghgemissions/understanding-global-warming-potentials#Learn%20why. Each greenhouse gas has a different life span and a different warming potential. This site explains the metric used for comparing greenhouse gases and their contribution to the problem of climate change. Carbon Dioxide is the base greenhouse gas, assigned a value of "1" against which all other gases are compared.

World Weather Attribution, Accessed July 2020. www.worldweatherattribution.org World Weather Attribution studies specific weather events and determines the level to which they believe the event was connected to climate change. They make a determination whether there was an increased likelihood that an event occurred due to climate changes or were more intense due to climate changes.

Endnotes

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[1] "Henry C. Lea School" School District of Philadelphia. Accessed June 14, 2020. https://dashboards.philasd.org/extensions/philadelphia/index.html#/

[2] "Henry C. Lea School" School District of Philadelphia. Accessed June 14, 2020. https://dashboards.philasd.org/extensions/philadelphia/index.html#/

[3] Ayanna Elizabeth Johnson "I'm a Black Climate Scientist" Washingtopost.com, June 3, 2020. https://www.washingtonpost.com/outlook/2020/06/03/im-black-climate-scientist-racism-derails-our-efforts-save-planet/

[4] "Fourth National Assessment Summary Findings" United States Global Change Research Program, Accessed July 2020. https://nca2018.globalchange.gov

[5] Aaron Bernstein. "A Conversation on COVID-19 with Dr. Aaron Bernstein, Director of Harvard Chan C-CHANGE" Harvard University C-Change Center School of Public Health, n.d. "Coronavirus, Climate Change, and the Environment: Accessed June 2020. https://www.hsph.harvard.edu/c-change/subtopics/coronavirus-and climate change/

[6] "Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II " Ebi, K.L., J.M. Balbus, G. Luber, A. Bole, A. Crimmins, G. Glass, S. Saha, M.M. Shimamoto, J. Trtanj, and J.L. White-Newsome, 2018: Human Health. U.S. Global Change Research Program, Accessed July 29, 2020. https://nca2018.globalchange.gov/chapter/14/

[7] "Overview of Greenhouse Gases Methane Emissions" Environmental Protection Agency, Accessed July 2020. https://www.epa.gov/ghgemissions/overview-greenhouse-gases#methane.

[8] Hope Jahren, The Story of More (Penguin Random House.),) 30-31.

[9] Hope Jahren, The Story of More (Penguin Random House.), 32-33.

[10] Hope Jahren, The Story of More (Penguin Random House.), 45,71.

[11] "Human Development Report 2019" United Nations Development Programme, Accessed July 2020, 178. http://hdr.undp.org/sites/default/files/hdr2019.pdf

[12] "IPCC" Intergovernmental Panel on Climate Change. Accessed June 2020. Ipcc.ch.

[13] "Sixth Assessment Report" Intergovernmental Panel on Climate Change. Accessed June/July 2020. ipcc.ch

[14] "The Study of Earth as an Integrated System" NASA Climate.gov. Accessed July 15, 2020. https://climate.nasa.gov/nasa_science/science/

[15] "Global Temperature" NASA Global Climate Change: NASA's Goddard Institute for Space Studies (GISS). https://climate.nasa.gov/vital-signs/global-temperature/

[16] "Understanding Global Warming Potentials" Environmental Protection Agency, Accessed July 2020. https://www.epa.gov/ghgemissions/understanding-global-warming-potentials#Learn%20why

[17] "Global Greenhouse Gas Emissions Data" Environmental Protection Agency. Accessed July 2020. https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data and https://www.ipcc.ch/report/ar5/wg3/

[18] "Overview of Greenhouse Gases Methane Emissions" Environmental Protection Agency, Accessed July 2020. https://www.epa.gov/ghgemissions/overview-greenhouse-gases#methane.

[19] "Overview of Greenhouse Gases Nitrous Oxide Emissions" Environmental Protection Agency, Accessed July 2020. https://www.epa.gov/ghgemissions/overview-greenhouse-gases#methane.

[20] "Overview of Greenhouse Gases Carbon Dioxide Emissions" Environmental Protection Agency, Accessed July 2020. https://www.epa.gov/ghgemissions/overview-greenhouse-gases#methane

[21] Rebecca Lindsey "Climate Change: Atmospheric Carbon Dioxide" National Oceanic and Atmospheric Administration. Climate.gov. February 20, 2020. https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide

[22] Environmental Protection Agency, Accessed July 2020. https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

[23] "Weather vs. Climate" National Oceanic and Atmospheric Administration. Accessed July 2020. https://www.ncei.noaa.gov/news/weather-vs-climate.

[24] "Summary Report for Policymakers on Climate Change and Land" Intergovernmental Panel on Climate Change. https://www.ipcc.ch/srccl/chapter/summary-for-policymakers/

[25] "Chapter 25: Southwest" Fourth National Climate Assessment. Accessed July 2020. https://nca2018.globalchange.gov/chapter/25/

[26] "Chapter 18: Northeast" Fourth National Climate Assessment. Accessed July 2020. https://nca2018.globalchange.gov/chapter/18/

[27] “About World Weather Attribution” World Weather Attribution. Accessed July 2020. https://www.worldweatherattribution.org/about/

[28] “Attribution of Australian bushfire risk to Anthropogenic Climate Change.” World Weather Attribution. January 10, 2020. https://www.worldweatherattribution.org/bushfires-in-australia-2019-2020/

[29] “Latest Analyses” World Weather Attribution. July 27, 2019, August 2, 2019, July 2, 2019.https://www.worldweatherattribution.org.

[30] “Climate Change Adaptation” City of Philadelphia. Accessed July, 2020. https://www.phila.gov/water/sustainability/Pages/ClimateChange.aspx

[31] “Asthma Capitals 2019” Asthma and Allergy Foundation of America. Accessed July 15, 2020. https://www.aafa.org/asthma-capitals-top-100-cities-ranking/

[32] “Climate and Health” Asthma and Allergy Foundation of America. Accessed July 29, 2020. https://www.aafa.org/climate-and-health/

[33] Suzie Boss, John Larmer, and John Mergendoller PhD. PBL for 21st Century Success. (Buck Institute of Education, 2018), 25-26.

Appendix on Implementing District Standards

Pennsylvania State Standards addressed by this unit

S8.A.3.2.2 Describe how engineers use models to develop new and improved technologies to solve problems.

Students will develop a plan to retrofit their school building to adapt to and mitigate climate change. In order to display their choices, students will create models and justify the choices they made. Students will also conduct scientific investigations to develop understandings that will help them construct models.

S8.B.3.3.1 Explain how human activities may affect local, regional, and global environments.

Students will be exploring climate change and will observe a direct correlation between fossil fuel combustion and consumption, the increase in greenhouse gases. In this unit students will focus on local impacts in Philadelphia, but will ultimately be able to make connections to larger issues with a strengthened set of background knowledge.

S8.C.2.2.3 Describe the waste (i.e., kind and quantity) derived from the use of renewable and nonrenewable resources and their potential impact on the environment.

While hard to see, greenhouse gases emitted during fossil fuel combustion are a waste product of a non-renewable source. Students will be exploring climate change current and potential impact on the environment of Philadelphia.