Keeping Our Cool:
Studying the Statistics of Climate Change

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This curriculum unit is recommended for Math 8, Math 7 Honors

Keywords: climate, stabilization wedge, bivariate data, scatter plot, two-way table

Teaching Standards: See Appendix 1 for teaching standards addressed in this unit.

Synopsis: This unit uses statistical analysis to examine and interpret climate change. Students begin by learning about how we measure climate data, using scatterplots as a tool to understand weather compared to climate, evaluate and make predictions based on trends, and uncover other effects of climate change beyond temperature increase. Using the concept of stabilization wedges, students create scatter plots examining the viability of decreasing carbon emissions by 2050, creating a line of best fit to predict future data points. Students complete the unit by using two-way data tables and two-way frequency tables to compare opinions on climate change.

I plan to teach this unit during the coming year to 89 students in Math 8.

Keeping Our Cool: Studying the Statistics of Climate Change

Cannon Shipman

Introduction

At the time of writing this unit, over four million students are striking globally--skipping school in protest[1]. A fifteen-year-old Swedish student at the forefront of the movement paints a stark, dire picture of our future: "People are suffering, people are dying, entire ecosystems are collapsing. We are in the beginning of a mass extinction and all you can talk about is money[2]." The catastrophe she speaks of? Man-made climate change, and its far reaching effects.

However, what role do such dark words play in the experience in the average student as they try to understand the complexities of our climate and its variations? For the large majority of U.S. students who live in urban settings, do they have a connection to how this reaction will impact their lives? Even more than this, how can today's youth continue moving beyond harrowing words into action?

The aim of this unit is to equip students with the statistical skills and scientific literacy to begin answering each of these questions, providing eighth grade math students in Charlotte an opportunity to explore climate science and a methodology for moving forward as a changing world. While climate change is a topic that is constantly discussed in today's news, this unit would give students the opportunity to examine data for themselves and draw conclusions, further examining the numbers behind certain solution strategies and comparing their effectiveness. By gaining these skills, the hope is to move beyond the fear-based proselytizing that seems to hallmark much of modern climate discussions. Instead, scholars develop a focus on understanding and creating a path forward. Coupled with measures to get students outside, proximate and interested in their local environment, this power of analysis enables students to engage in the changing world.

School and Student Backgrounds

This curriculum will be introduced to students in eighth grade math at Cochrane Collegiate Academy (CCA). Located in Northeast Charlotte, North Carolina, CCA encompasses grades six through twelve. The middle school is zoned through the neighborhood, and the high school functions as a technology-focused magnet program, though many students continue on to attend both schools. All students at Cochrane have access to Google Chromebooks through Charlotte-Mecklenburg Schools' 1-to-1 program. The middle school's classes are made up of 50 minute blocks, though this material can be adapted to other time frames.

Cochrane consists of students from a wide range of backgrounds, though the majority of students are considered economically disadvantaged. The CCA student body is made up of 928 students, with 58% of students identifying as Hispanic, 32% as African American, 4.3% as Asian, 4.0% as White, and the remaining students identifying as multiple races, American Indian, and Pacific Islander, in that order of incidence. The student body is disproportionately spread across each of the schools, with the middle school making up 68% of students. Approximately one-quarter of students at Cochrane are English Language Learners, and about one-tenth of students have a disability that affects their learning. With at least 75% of students' families at or below the poverty line, CCA qualifies as a Title I school, meaning students are provided with extra assistance including but not limited to free lunch, extra supplies, and access to assistance programs as needed.

The first students to engage with the curriculum unit will be three standard mathematics classes, consisting of 89 students in all. The classes are made up of a variety of learners, including students with disabilities and about one-third of students who are ELLs. Approximately 94% of students in the classes are below grade level in math, according to the previous year's data, necessitating curriculum that will simultaneously reloop material while introducing concepts for the grade level that demonstrate appropriate rigor. Once successfully implemented with this group of students, the curriculum will be introduced to the entire eighth grade math department the following year, just over 200 students.

Unit Goals

This unit is designed to cover the entirety of eighth grade statistics and probability standards, while students simultaneously investigate current research in climate science. Eighth grade statistics standards expect students to find patterns in bivariate data, which also consists of finding and examining lines of best fit, clusters, and outliers to more accurately interpret the meaning of the graphs (Appendix 1). Additionally, by the end of the unit students should be able to represent categorical bivariate data in a two-way table, finding frequencies and relative frequencies. As statistics is the final eighth grade unit, this would provide an excellent tie-in to previous content in students' mathematics classes, continuing to reloop and review content, particularly functional graphs (linear and nonlinear), interpreting stories of graphs, and examining samples and populations.

This unit will be broken into three main concepts, each centered around a guiding question. The first concept is an introduction to the fundamentals of climate science and of bivariate data as a concept, or, "How can we use representations of data to understand climate change?" Students will be expected to understand the following over the course of a week's classes: climate compared to weather, evidence that the climate is changing, what climate change impacts, and some predictions of how climate change will affect the world. Students will investigate each of these concepts through creating and interpreting scatter plots.

As a second concept in the unit, students use problem-based learning to examine solution strategies, focusing on the question, "How can we use statistics and mathematical reasoning to compare solution strategies for climate change?" They are introduced to the $I=P*A*T$ relation and stabilization wedges, developing a general understanding of how each adds to discussions on climate change. Students will then use a scatter plot to investigate a stabilization wedge, integrating a line of best fit to predict future data points, with the goal of finding the eight stabilization wedges needed by the year 2050.

Students will complete the unit by examining visual representations of climate science data, and analyze views of climate science using two-way data tables. They will compare their answers at the beginning and end of the unit, and see how their data compares to other data sets by calculating frequency tables. The question will be, "How can we use two-way frequency tables to understand opinion about climate change?"

There is opportunity to expand cross-curricular alignment naturally found in a mathematics unit on climate change. This could include everything from teachers adding on a section of the project integrating their standards, to be a full day of programming surrounding students' projects and tying in each subject.

Content Research

Concept 1: Fundamentals of Climate Science

Before one can analyze how to approach climate change or even the mechanisms of climate change, it is crucial to first develop an understanding of climate itself.[3] Put succinctly, weather is what's happening atmospherically at any specific point in time, but climate is the average over long periods, including both temperature and precipitation as primary components. Climate change is any change in the average when comparing two periods of time. While students will be primarily focused on the measurements and data associated with climate change, it is helpful for educators to have a general understanding of the science behind the numbers, to create richer evaluation of the material through class discussions and curriculum extensions.

A Basic Climate Model

As a most basic climate model, the amount of energy received by a planet from the sun must be balanced with the amount that radiates out to space. When an atmosphere is introduced that is transparent to the sun and radiates energy equally upwards and downwards, the planet's surface has to emit more heat in order to radiate the same amount out as it receives in solar energy, which in turn warms the planet. The more atmospheric layers we have in this model, or, in other words, the higher the percentage of greenhouse gases we have, the warmer the planet is. A clear example of this phenomenon can be seen in the temperature of Mercury compared to the temperature of Venus. Though Mercury is much closer to the sun and absorbs far less light due to its darker color, Venus is over 300°C warmer because of a massive, greenhouse-gas rich atmosphere.

Only a tiny fraction of the total mass of our atmosphere consists of greenhouse gases: water vapor, carbon dioxide, methane, nitrous oxide, ozone, and halocarbons. Even within this mix of greenhouse gases, the amount and longevity of each gas affects which gases disproportionately contribute to the warming associated with greenhouse gases. For example, halocarbons have the strongest greenhouse effect, but are present in infinitesimally small quantities to make it far less of a contributor to climate change. Likewise, methane is a greenhouse gas contributed by humans that is stronger than often-mentioned carbon dioxide, but it leaves the atmosphere much more quickly. Carbon dioxide, on the other hand, is a perfect perpetrator, existing in large enough quantities and creating long-lasting atmospheric changes.

Therefore, to more fully understand the effect of carbon dioxide and how it contributes to warming, it becomes integral to understand the carbon cycle. The carbon cycle describes the biological, chemical, and geological processes that convert carbon in the atmosphere to carbon in the land, mixed and deep layers of the ocean, and rocks. The atmosphere stores carbon primarily as carbon dioxide and exchanges it relatively quickly with the land and surface ocean waters. The deep ocean and rocks take up atmospheric carbon much more slowly, but also store much more carbon in total. The fossil fuels humans use are part of the large stores of rock carbon, with us essentially creating a new component of the carbon cycle that moves carbon from rocks to the atmosphere much more quickly. Because the pathways that move carbon from the atmosphere back into the rocks are very slow, this fossil fuel carbon accumulates in the atmosphere and remains there for centuries or longer.

The increased atmospheric carbon then changes the energy balance on earth, and the earth adjusts its temperature to return to the energy balance. This in turn triggers positive and negative feedbacks from the carbon cycle that amplify the changes in one direction or the other. For example, the melting of permafrost releases stored carbon dioxide and contributes even more to the energy imbalance, adding to the temperature change. Positive feedbacks (an increase in carbon) are expected to outweigh negative feedbacks in our changing climate, leading to a doubling or tripling of the initial warming from our CO_2 emissions. Because the warming from the increased atmospheric carbon affects so many systems, particularly systems that are slow to change, its total effects will still be seen a millennium from now.

Measuring Climate Change

To find climate change, scientists (and our student investigators) must examine a specific combination of measurement data. Generally, scientists use temperature anomalies, the difference above or below average, as the primary measure of comparison in researching climate change. This is because anomalies are less variable across locations than temperature averages and require fewer resources to accurately document. To compensate for uncertainties and inconsistencies with surface thermometers, many researchers use a variety of measurements, including satellite temperatures, ocean temperatures, and the melting of ice, whether it is glaciers, sea ice, ice sheets, or grounded ice (measured through sea level). To compare rising temperatures to the earth's long-term climate history, scientists also use paleoproxies. These are trees, ice cores, and ocean sediments, which have past climate indicators imprinted in their geological, chemical, or biological systems. These relatively independent data sets all indicate dramatic changes in today and tomorrow's climate, and compound to create evidence that cannot and should not be ignored for single instance or regional anomalies to the warming trend. In learning about general climate science, students will analyze bivariate data encompassing a multiple time periods and types of measurements, giving them practice interpreting a large number of scatterplots and allowing them to fully understand the strong, consistent evidence of climate change.

Over geologic time scales, long before humans entered the evolutionary timeline, the earth has been vastly colder and vastly warmer than it is today, through natural shifts in the planet's climate.[4] This inevitably leads to an examination of different suspects that could contribute to the aforementioned warming trend. Continental drift, variations in the Sun, orbital variations, and El Nino are all natural processes capable of changing the climate, but, as a whole, they all move much too slowly for us to be able to attribute the planet's warming to any of these (or, in the case of El Nino, do not provide evidence of causing lasting temperature changes).

Human-caused changes, on the other hand, almost perfectly match the change in temperature over the last couple centuries.[5] There are multiple ways that human intervention aligns with changes in climate. Most prominently featured are greenhouse gases, which alone account for the warming trends seen in the past century and a half. However, if greenhouse gases were humankind's only contribution, scientists would actually expect temperature increases to be about 30% more than observed; instead, the warming is offset by aerosols – microscopic particles in the atmosphere such as dust, smoke, and pollution – that cause atmospheric cooling by increasing the brightness of the planet as a whole and reflecting more sunlight back to space.

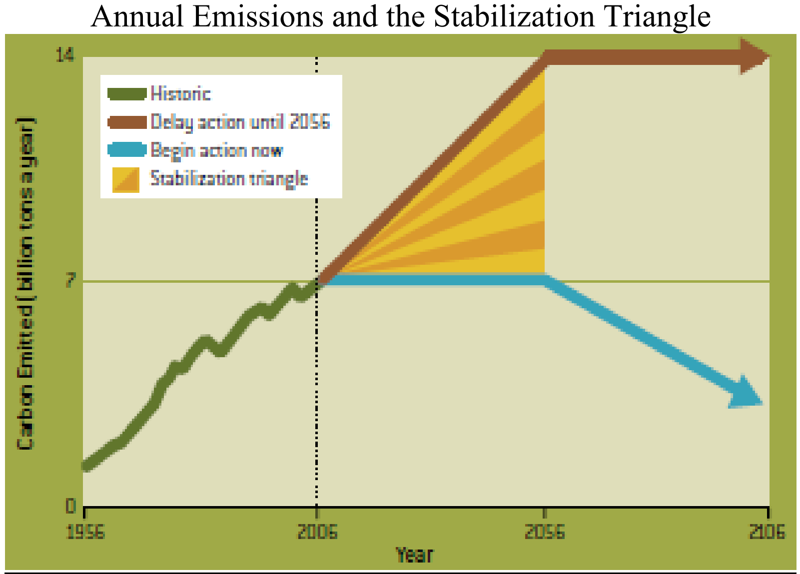
Concept 2: Solution Strategies and Stabilization Wedges

Given an understanding of the irreversible damage we risk as we continue to increase the carbon concentration in the atmosphere, an obvious next step is to begin researching potential solutions. Our greenhouse gas emissions (I) depend on population (P), affluence (A), and greenhouse-gas intensity (T), represented in the IPAT relation $I = P * A * T$. Therefore, to reduce greenhouse gas emissions, we need to reduce one of these three things. Because it is extremely politically unfeasible and generally undesirable to campaign for a reduction in affluence or population, we are left to combat greenhouse gas intensity, further broken down into energy intensity (energy consumed per dollar spent) and carbon intensity (technologies we use to create energy).

Depending on how much we reduce our emissions, there are several scenarios that our future could look like in terms of global warming, ranging from 1.8-4.2 degrees celsius in the next century alone. Generally, many scientists and climate activists begin by envisioning two fifty-year potential futures. One of these has the rate of change increasing at the same rate it is now, reaching three times pre-Industrial levels of carbon concentration. The other, more optimistic version continues at today's rate, then declines, avoiding the worst case-scenario.[6]

FIGURE 1[7]

Annual Emissions and the Stabilization Triangle



The orange-yellow triangular space between these two lines is called a stabilization wedge, the ground technology and society must gain to reduce emissions to a necessary level in upcoming years. Scientists have created a series of seven wedges, each representing 1 billion parts per million (ppm) of carbon that technology will need to avert emissions. Each wedge must be directly in response to climate change, not efficiencies or averted emissions that would happen independently with improving technology. They also must be technologies that already actually exist, but would need to be scaled or applied differently! Key first steps lie at the heart of electricity consumption, by decreasing coal power plants' emissions (through reductions in plants or carbon-capture) and increasing electric efficiency. There are at least fifteen wedges now (Figure 2), and also potential to create new wedges in the next fifty years as technology develops.

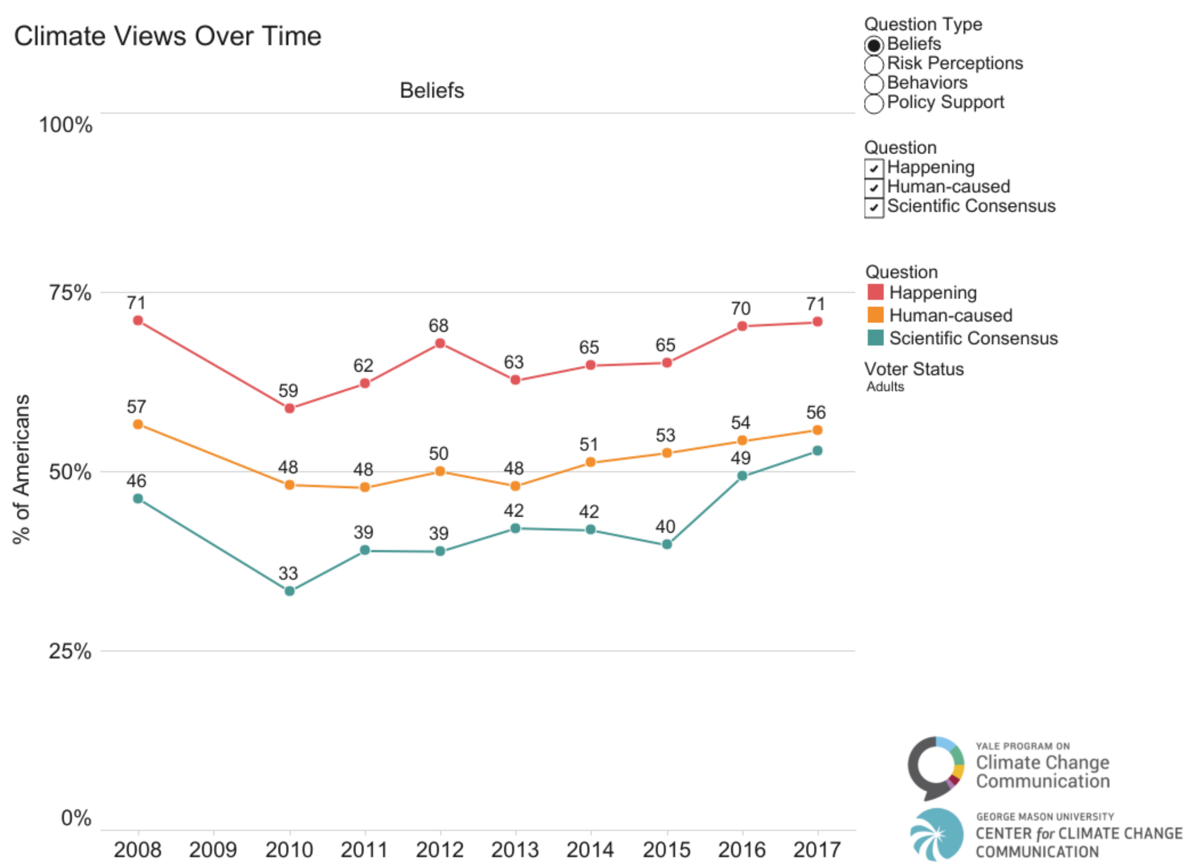
FIGURE 2[8]
15 Ways To Make a Wedge

It is important to note that stabilization wedges are not quite as clear-cut as these charts make them out to be. It will be a challenge to implement them while continuing to increase economic growth, and even more so to force rate reductions without disproportionately affecting the economies of developing countries. Not only that, but the wedge vision is only addressing the climate crisis in fifty-year increments, and we should view the following fifty years as the next leg of a race with the same amount of challenge.

Concept 3: Views of Climate Change

Though the reports published by the Intergovernmental Panel on Climate Change and other associations in the scientific community achieve a relative consensus on the reality and impact of climate change, general opinion is not as unified. While over two-thirds of Americans currently believe that climate change is happening, research published by Yale University's Program on Climate Change Communication suggests that only about half of adults believe it is human-caused, and even fewer are aware that there is a scientific consensus.[9]

FIGURE 3
Climate Views Over Time[10]



What causes this discrepancy? When coming to conclusions about information, we cannot possibly have all knowledge about all fields, so we frequently rely on shortcuts to form our opinions. This includes relying on firsthand experience, values, opinion leaders, or, most commonly, experts in the field, particularly when experts are in agreement. There are many outlets on the web that attack scientific consensus, using unqualified "experts" to create confusion about the science, similar to that which delayed policy action surrounding the negative health effects of tobacco products. Furthermore, scientific conclusions tend to be written much more conservatively than conclusions from the general public, which can add additional misunderstanding of the situation's depth and urgency. Finally, the tendency to rely on firsthand experience can hinder a public consensus of climate science, since climate changes occur over periods of time.

Instructional Implementation

General Classroom Strategies

Conceptual Math

Learning math conceptually means that students are focusing on the *why* behind the numbers. They can flexibly break down numbers they are working with to find connections, and can provide mathematical reasoning and logic for why they are using the operations they are using.[11] This is contrasted with procedural learning, where students are spending the majority of their time learning, applying, and practicing a list of rules--an approach that focuses on the *how*. Research demonstrates that the conceptual piece is key to long-term mathematical understanding, as it helps students to see the subject as a way to solve complex problems, instead of simply sets of unrelated formulas to memorize. In the words of mathematician Reuben Hersh, "Mathematics is learned by computing, by solving problems, and by conversing, more than by reading and listening."[12] Therefore, the majority of this unit will focus on the conceptual component of mathematics, particularly through methods of problem-based learning and mathematical conversations.

Problem-Based Learning

Problem-based learning consists of students engaging with math concepts through the act of solving a problem. This takes advantage of students' natural inclination toward curiosity and ability to make sense of things--in other words, their natural problem-solving skills. This allows students to practice their analytical competence, working to apply a variety of techniques to solve a problem, many times using different strategies to find their answer. For example, in this unit, instead of telling students what a scatterplot is and how to use it, students first examine bivariate data in a table and hypothesize for themselves about the best way to represent the relationship. The technique of problem-based learning can also be applied in longer projects, such as the stabilization wedges research students will complete at the end of the unit. Problem-based learning has been shown to increase student interest and motivation, while allowing students to see the connections between different parts of mathematics in an oftentimes real-world situation.[13] Not only that, but problem-based learning gives an extra opportunity for educators to personalize learning for the student, whether through interest or mastery level.

Mathematical Conversations

Another key component of conceptual understanding is the ability to discuss math. This involves "asking good questions, rephrasing problems, explaining ideas, being logical, justifying methods, representing ideas, and bringing a different perspective to a problem."[14] Student discussions should be interwoven throughout the content of this unit, with full-class discussions during the lesson summary each day. Some supportive questions are provided, but educators are encouraged to add their own questioning as needed. During each lesson, there are opportunities for group or partner work, with unstructured mathematical collaboration between students seated together, and there are also more structured conversations. For example, many of the guiding questions can be used as "Think, Pair, Share," where students should think or write on their own, talk through their answer with a partner, and then share with the entire class. Additionally, the "Notice & Wonder," routine lets students interpret patterns and make meaning of new mathematical concepts through the observation of things they notice and things they wonder.

Extra Practice

Because students are spending the vast majority of their class time on conceptual learning, whether it be problem-solving using the math or discussions breaking down the meaning of the numbers used, teachers generally need to look outside of the school day for extra practice. For procedural work, it is recommended that teachers utilize homework, allowing for additional chances to build fluency with the problem-solving techniques that are learned in class through practice problems. Students can also use notes to increase understanding and review material. Notes can be added to each day during the lesson reflection, as the class goes over key concepts and definitions, and can be as formal or informal as is established in the classroom. For example, my classroom uses Cornell Notes for each unit, so students will highlight key concepts each day through filling in this unit's Cornell Notes.[15]

Classroom Lessons and Strategies

Day 1 (Concept One)

For their first lesson, students are introduced to the concept of bivariate data and primed on prior knowledge of climate change. Students examine different visual representations of data associated with climate change, and analyze what information they show, how they show the information, and the pros and cons for each. Finally, students are shown their first scatter plot and create one of their own.

Warm-up: Students' warm-up on Day 1 will consist of filling out the four questions that make up Yale University's Six Americas Super Short SurveY (SASSY; Appendix 2).[16] Educators are encouraged to use an online tool such as a Google form to have students fill this survey out, as results can then immediately be uploaded and analyzed on the SASSY website. This warm-up primes students for discussions on climate science and climate change by allowing them to express their opinions. It also gives a beginning data point to be used for two-way tables and an examination of changing opinions as the unit continues.

Introduction: Show a table of climate data on Mecklenburg County (Appendix 3); have students write and discuss what they notice and what they wonder about the data. Then, ask students what method of visualizing data would work best. If students are having trouble, facilitate a brainstorming session on different methods they have used in previous classes, such as box plots, histograms, and dot plots. Introduce students to the unit question, and explain how we are going to spend the next few lessons exploring what exactly climate science is, and what can be done about climate change. If time, a short video from the news or pop culture highlighting climate change would be helpful here as part of the unit introduction.

Gallery Walk: Introduce students to the concept of a gallery walk reviewing different data visualizations describing facets of climate change (Teacher Resources).[17] As students walk around and examine each data display, they will complete a reflection sheet on at least four different graphs, comparing how they display data and what types of data they can display (Appendix 4). Bring the class back together, and allow students to share thoughts with a partner and the class. Show students the graph documenting the Mecklenburg County temperature variation, and discuss the merits of representing data this way. Potential questions include:

- What patterns do you see in the graphed data?[18]
- How could you use the graph to estimate the average temperature in 2000? In 2030?

Lesson Summary: For the lesson summary, hold a class discussion on the characteristics of data that scatter plots can help us analyze, introducing them to the term bivariate data.

Extension: The introduction to the fundamentals of climate science would ideally be paired with an exploration of a local climate, to connect learning outside of the classroom. It is strongly encouraged that educators who have the freedom within their schedule create an opportunity to interact meaningfully with their own climate.[19] This could include planning a field trip that would familiarize students with local climate, such as a greenhouse or a national park, or could be as simple as a nature walk through school grounds.[20] Any of these activities has the potential to tie into the learning of the unit while creating a more personal connection to the climate they are examining--crucial when developing an understanding and motivation surrounding climate change.

Day 2 (Concept One)

On day two, students will continue to practice creating their own scatter plots, using a modified version of NASA's "Graphing Global Temperature Trends" classroom activity.[21] Students will compare smaller time frames of climate data to interpret positive, negative, and no correlation. They also focus on interpreting scatterplots by reviewing linear and nonlinear functions. This lesson culminates in students combining each era into a complete timeline, therefore understanding that, though trends may appear different when zoomed out, there is a clear positive correlation when looked at altogether.

Warm-up: Each student reads through the article at the beginning of the "Graphing Global Temperature Trends," further familiarizing students with using scatter plots to represent climate data. Students should have access to a highlighter to take note of important learnings in the article, and should answer the following questions:

1. What does the article tell us about how we can measure climate change?
2. How could we use a scatter plot to represent this information?

Activity (created by combining the two lessons in "Graphing Global Temperature Trends):

1. Explain to students that they will be analyzing Earth's average temperatures for the past 136 years, divided into months, but each group will only be looking at ten years of that data.
2. Distribute the global monthly temperature data, pre-divided for individuals or groups into ten-year sections, along with graph paper.
3. Explain that the class will combine all their graphs into one giant graph representing the entire 136-year trend. Because their graphs will be combined with the graphs from the rest of the class, everyone must use the same horizontal and vertical scale.
4. As a class, examine the data to determine which value, date or Global Land and Ocean Temperature Anomaly in °C, should go on the vertical axis. Although it technically can be done either way, monthly temperature anomaly should go on the vertical axis for ease of viewing. Lead students in a discussion about the variables used, using the following information:
    a. "The first column contains date information. The first four digits represent the year and the last two digits represent the month:
    188001= Jan 1880
    188002 = Feb 1880
    .
    .
    .
    188012 = Dec 1880
    b. The second column is the Global Land and Ocean Temperature Anomaly in °C, compared with the average temperature, 13.9°C, from 1901 to 2000 [though the actual dates are 1880 to 2016]. Explain to students the concept of anomaly and why scientists often use this instead of actual temperature readings."[21]
5. Once students understand the variables, lead them through the process of determining appropriate vertical and horizontal scales for their graph, creating a graph of your own as an exemplar.
6. Have students begin graphing their data, monitoring their work. If students are having trouble getting started, it may be necessary to do an example graph together, such as the last six-year period.
7. When students finish their graph, have them complete the questions in Appendix 5, which can be printed on the back of the graph paper.

Lesson summary: Have students tape graphs together on a wall or white space to show the entire 13-year period. Synthesize the lesson by reviewing the following questions in a "Think, Pair, Share" format:

- Does the data for all 136 years show a positive, a negative correlation, or no correlation? How does this correlation compare with the trend you saw for your ten-year period?
- Is the trend linear (constant) or nonlinear?
- When does the correlation change? Why might it change at that point in history?
- How is this activity helpful in comparing weather and climate? How does scale affect these? *Students may need to be reminded of the difference between weather and climate.*
- Using the data we compiled, what would you expect the temperature anomaly (how much above or below average) would be by 2025?

Finish the discussion by watching the video included within the lesson, "Earth Has a Fever," which emphasizes the meaning behind a temperature change of several degrees, and begins explaining the effect such a change will have on the planet.[22]

Day 3 (Concept One)

On their third day of the unit, students will continue to examine scatterplots, becoming more specific in the language they use to discuss trends and points on the graph. Students also see graphs that do not include date as one of the variables, to ensure they understand all scatter plots are not using time. While working towards these mathematical goals, students explore the effects of climate change outside of temperature increase.

Warm-up: Project the graph from Day 1, with a point circled (Appendix 3). Have students answer the following question: "What does this point on the graph tell you about temperature in North Carolina?" Give students one minute to write their answer, followed by one minute to compare their answer with a partner's, leading into full-class discussion.

Activity 1: Students will be given a set of unlabeled graphs showing a strong positive correlation, a negative correlation, no correlation, and a weak positive correlation.[23] They will also be given a set of x- and y-axes labels to match to the graphs (Appendix 6). Students will work with partners to match each pair of axes with one of the graphs, explaining why they chose the graph they did, using mathematical language when possible. Once the teacher has checked their matching, students complete the remaining questions, continuing to examine the scatter plots and explain their reasoning.

Activity 2: Students are given a graphed data set about forest fires (Appendix 7).[24] If there is time, students can receive only a table and complete a scatter plot themselves.[25] Students then answer questions describing and analyzing the trends shown in the scatter plot. They are introduced to the concepts of outliers and clusters.

Lesson summary: Today's lesson summary should be primarily reviewing vocabulary within the unit so far: scatter plot, bivariate data, correlation (and examples), outlier, and cluster.

End activity: This activity can be used as a check-in, assessing student understanding so far in the unit. Give students a small paper with a graph drawn and the following questions:

1. Sketch a scatter plot that shows the approximate relationship between global temperatures and sea level. Include and label either a cluster or an outlier.
2. What type of correlation does your graph show? How do you know?
3. Is your relationship weak or strong? How do you know?

Day 4 (Concept One)

Day four introduces lines of best fit, along with the linear and nonlinear data in a scatter plot. Students begin by informally predicting future points, getting ready for identifying and drawing a line of best fit later in the lesson. Students use this mathematical reasoning to examine potential causes of climate change, comparing a line representing general temperature change to a variety of other variables that could be contributing factors. Students then draw their own line of best fit.

Warm-up: Students again analyze the original graph of temperature change in Mecklenburg County, answering the questions:

1. If you had to predict the temperature for 2025, what would you say? What contributed to your prediction?
2. What is your prediction for 2050?

Give students two minutes to answer, followed by one minute to compare their responses with a partner's, leading into full-class discussion.

Activity 1: Students are shown a scatter plot showing temperature trends over the past century.[26] On the scatter plot are five lines showing components of a changing climate, both human-caused and natural. Students should not be able to see key identifying the lines at the beginning of the activity. Students should identify which line fits best with the observations, explaining their reasoning to a partner. Show the students the key, and synthesize the activity as a class. Then, introduce the formal definition of a line of best fit, linear trends, and nonlinear trends.

Activity 2: Students are given another copy of the Mecklenburg County climate data (Appendix 3). Using a ruler, students are instructed to create a line of best fit, and find the equation for the line, drawing on earlier eighth-grade standards on linear relations. As students complete this activity, have an anchor chart up defining line of best fit.

Lesson summary: Show students an example answer from Activity 2. Have students discuss the following questions with partners, then as a class:

- How did you know whether your line of best fit was correct?
- How did you create your equation for your line?
- What is the slope of your line? The vertical intercept?
- How could I use my line to predict the average temperature in Mecklenburg County next year? In 2050? *Note: students can use either the graph of the line or the equation of the line to find the answer to this problem. Try to highlight students using each strategy in class discussion.*
- Does the data appear to be linear or nonlinear? How can you tell?

Days 5-8 (Concept Two)

Students will spend the next four days completing a project using the statistics they have learned so far. Placed in groups of four, their goal will be to work as a team to come up with the eight stabilization wedges that they think will be best to reduce emissions. To do this, classes will use "Stabilization Wedges: A Concept & Game," developed by Princeton University's Climate Mitigation Initiative.[27] However, they must expand on the conclusions the game requires, creating scatter plots representing each chosen wedge (two per student). This project allows students to look forward to what can (and hopefully will) be done about climate change, while utilizing the skills covered in bivariate data. It can be used as an assessment for Concept One and Concept Two of the unit if desired.

Day 5: Students are given their group assignments. Introduce students to the IPAT relation and the idea that we have control of where climate change goes from here. The class should then follow the "Introduction" procedures from "Stabilization Wedges: A Concept & Game." Because there has been at least a week of similar content, students should be able to move into the "Playing the Game" procedures, and complete "Filling in the Stabilization Triangle" by the end of class. Teachers should check student guides before moving on to the next part of the lesson.

Day 6: At this point, students should know the two resources they will be researching. Students are provided with graph paper, a straight-edge, and technology to find the data needed. Begin with a class discussion to review the purpose of the scatter plots students are making: they tell us, based on current trends, if we are on the path to enact this stabilization wedge by 2050. For example, a student investigating Wedge 4: Electrical Efficiency might investigate trends in electrical plan efficiency over the past 70 years, and then draw a line of best fit to determine if current trends will have us at 60% efficiency by 2050. Consider asking the following to remind students of previous learning:

- What statistical component can we use to predict where our stabilization wedge will be by year 2050? *A line of best fit.*
- Jada created a scatter plot showing the trends over the last forty years of her chosen strategy. Kimalie's scatter plot shows the last eighty years. Whose scatter plot would you expect to be more accurate? *Kimalie's, because she has a longer, more nuanced view of the data--like when we did global temperatures.*

Day 7: Students repeat the previous day's procedures for their second stabilization wedge. Teachers are encouraged to support students who are falling behind by providing resources to assist in the research process: the variables students can examine, links to websites with the data, or even the data itself.

Day 8: Students work with their group to finalize presentations. Each student completes reflection questions based on their exploration (Appendix 8), and each group should create a final product. This can be a poster, a presentation booklet, or a digital slide deck, depending on the resources available. If there is time, students can give short presentations on the stabilization wedges they chose and their findings. To summarize the project, conduct a class discussion with the questions from "Closure/Assessment of Student Learning."

Extensions: If able, students should be encouraged to take action with their findings through presentations to others in the school or even to members of the community interested in impacting positive environmental change. This section of the unit would also be an excellent opportunity for a field trip exploring the technology students are researching, such as a solar farm.

Day 9 (Concept Three)

Days nine and ten focus on categorical bivariate data. On day nine, students are introduced to two-way tables using data from the Six Americas Super Short SurveY, comparing the same data represented in a table and bar graph. Students create a relative frequency table to compare opinions from each eighth-grade class.

Warm-up: Students retake the survey from the first day of the unit. This will be used in the final lesson to compare survey data.

Activity 1: Project a two-way table comparing students who are concerned about climate change to students who think climate change will affect them, created from student data on Day. Introduce the display as a two-way table. Ask the students why it might be called a two-way table, and then lead a discussion interpreting several numbers from the table. Give students one task card at a time to work through, spending about four minutes on each card, and passing them on when finished. Reflect on the activity as a class, considering the following discussion questions:

- What strategy did you use to match the tables and bar graphs?
- How could you tell what each number meant?
- What strategy did you use to create your own two-way table?

Activity 2: Show students a two-way table broken down by class. Ask students which class felt the most worried about climate change. Point out that classes are different sizes, which affects our ability to compare them. In situations like this, we want to find a *relative frequency*, which tells us the frequency in a certain category. Have students answer the following questions with a partner, edited to match you class data and culminating in a class discussion:

1. Which class felt the most worried about climate change? Explain how a relative frequency table helps us compare classes of different sizes.
2. What does the number ___ mean in the context of our table? What about ____?
3. Tierra tells Shavon that the number ___ means that ___ percent of eighth graders are worried about climate change. Do you agree with her reasoning? Explain why or why not.
4. Explain why every cell in the last column has a 100 in it. What does that number mean?
5. What would it mean if there was a row of 100's across the bottom of a relative frequency table instead?

Activity 3 (optional): Have students complete the "Are You Ready for More?" in OpenUp Resources Unit 6, Lesson 9.3.[28] This activity has students compare different representations of the same data, demonstrating how choice of data visualization can significantly affect how it is interpreted. For the purpose of this unit, it may help to give additional context behind the "Proposition" the data is referring to; for example, the bill could be tied in with one of the stabilization wedges seen in Concept Two.

Day 10 (Concept Three)

The final lesson continues examining and interpreting two-way tables and frequency tables. Students use these tools to compare their survey data before and after learning how to analyze climate data, and then compare their SASSY results to national audiences.

Warm-up: Students are given an incomplete two-way table, comparing the variables "Class" and "Worried about Climate Change." These should be the new numbers obtained through yesterday's warm-up. Students fill in the missing data and answer questions interpreting the table.

Activity 1: Students return to the same two-way table from the warm-up. First, they find the relative frequency by row to get the percentage in each class, as they did yesterday with the first data set. Next, students break down relative frequency by the column to find the percentage for "Climate Worry." Students answer questions interpreting each of these numbers, followed by a class discussion highlighting the different information shown by each table. Next, the teacher should display the previous day's frequency table. Lead a discussion on how data has changed from the unit. Why might that be?

Activity 2: Students are shown two-way tables with their data and national data on "Climate Worry," broken down by gender. Lead a discussion on how these could be compared. Would a relative frequency table work? Students create overall frequency tables for each set of data, and then compare the meaning of each table through a class discussion.

Unit Review and Assessment

The stabilization wedge project can be used as a formative assessment, but teachers are also encouraged to use other methods to include two-way tables as well. For a unit review, teachers should be mindful to use scatter plots that do not have time as one of the variables, to increase student exposure to other variables.

Appendix 1: Teaching Standards

Primary Standards: Statistics and Probability

Investigate patterns of association in bivariate data.

NC.8.SP.1 Construct and interpret scatter plots for bivariate measurement data to investigate patterns of association between two quantities. Investigate and describe patterns such as clustering, outliers, positive or negative association, linear association, and nonlinear association.

NC.8.SP.2 Model the relationship between bivariate quantitative data to:

- Informally fit a straight line for a scatter plot that suggests a linear association.
- Informally assess the model fit by judging the closeness of the data points to the line.

NC.8.SP.3 Use the equation of a linear model to solve problems in the context of bivariate quantitative data, interpreting the slope and y-intercept.

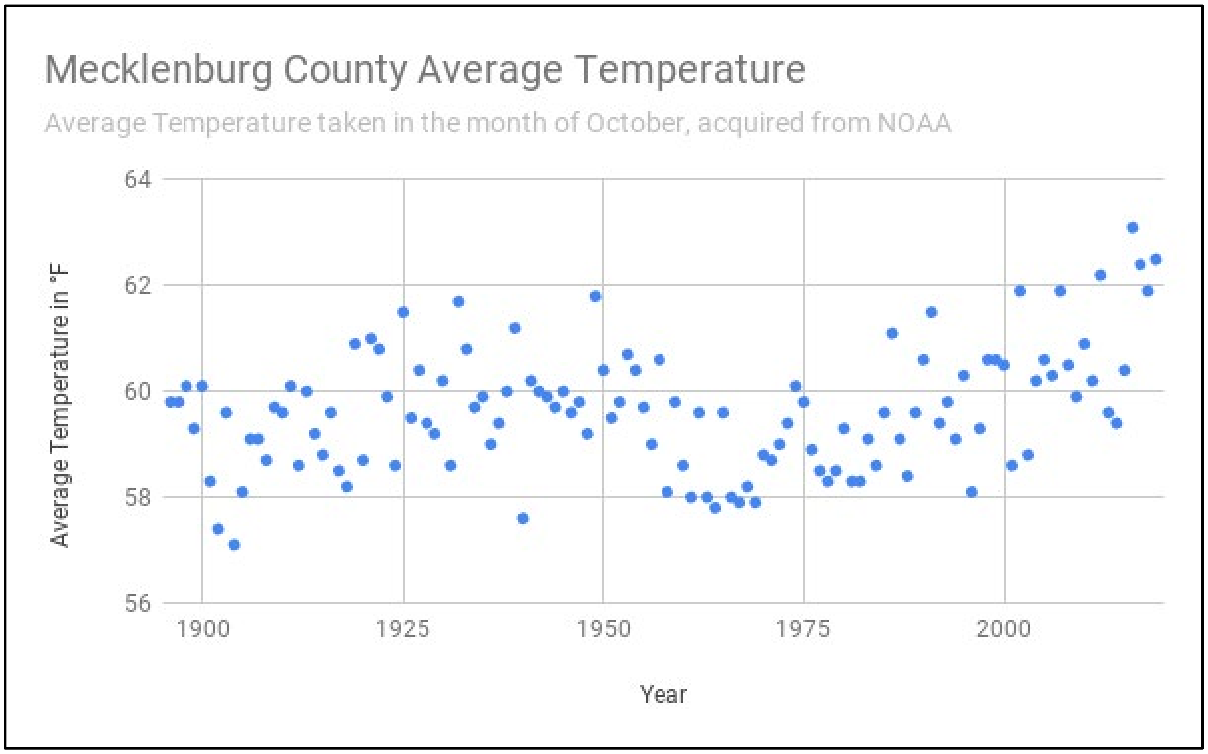
NC.8.SP.4 Understand that patterns of association can also be seen in bivariate categorical data by displaying frequencies and relative frequencies in a twoway table.

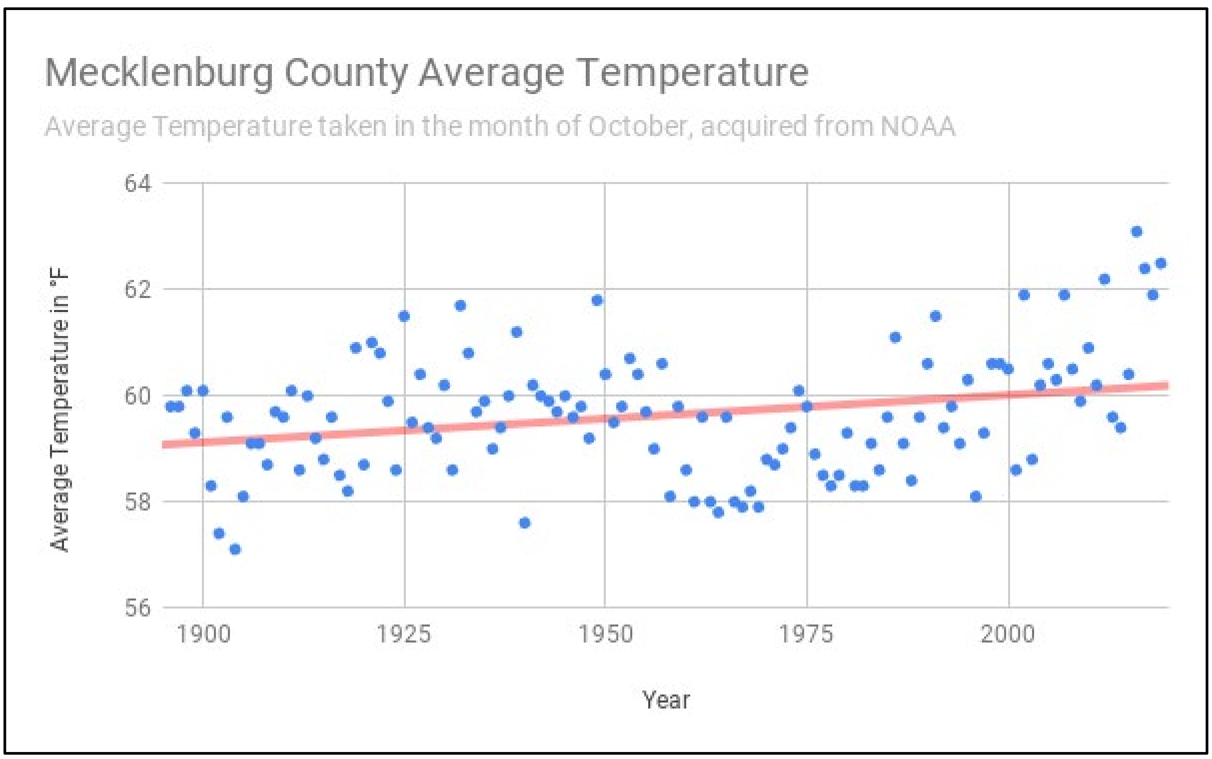
- Construct and interpret a two-way table summarizing data on two categorical variables collected from the same subjects.
- Use relative frequencies calculated for rows or columns to describe possible association between the two variables.

Appendix 2: Six Americas Super Short Survey (SASSY!)

1. How important is the issue of global warming to you personally?
    - Extremely important
    - Very important
    - Somewhat important
    - Not too important
    - Not at all important
2. How worried are you about global warming?
    - Very worried
    - Somewhat worried
    - Not very worried
    - Not at all worried
3. How much do you think global warming will harm you personally?
    - A great deal
    - A moderate amount
    - Only a little
    - Not at all
    - Don’t know
4. How much do you think global warming will harm future generations of people?
    - A great deal
    - A moderate amount
    - Only a little
    - Not at all
    - Don’t know

Appendix 3: Climate Data for Mecklenburg County[29]





Appendix 4: Data Visualization Gallery Walk

1. Chart Number: ______

   What information does this Chart display? ____

   ____

   ____

   How is the data visualized? ____

   ____

2. Chart Number: ______

   What information does this Chart display? ____

   ____

   ____

   How is the data visualized? ____

   ____

3. Chart Number: ______

   What information does this Chart display? ____

   ____

   ____

   How is the data visualized? ____

   ____

Appendix 5: Interpreting Global Temperature Trends

1. Explain, in your own words, what information your graph tells you.

2. What type of trend does your data make? Positive, negative, or none? Explain how you know.

3. How do you determine a scale for a scatter plot? What information is important to include?

4. What is the point furthest left on your scatter plot? What does this point represent in the context of the situation?

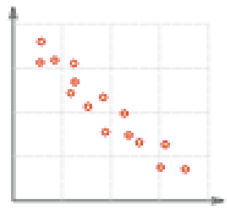
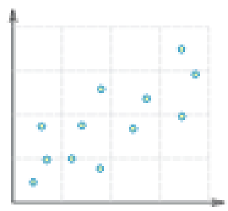
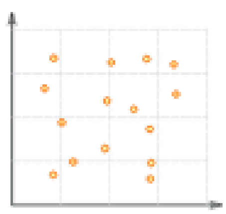
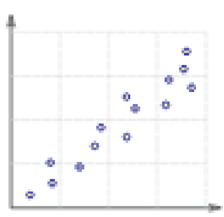
5. Which point shows the coolest year in your decade? How do you know?

6. How could you use this plot to estimate the next year's average temperature?

Appendix 6: Matching Scatter Plots with Variables

Instructions: Pair each scatter plot with the axis labels that most closely fit the trends shown. Below each match, explain how you know which sets went together.

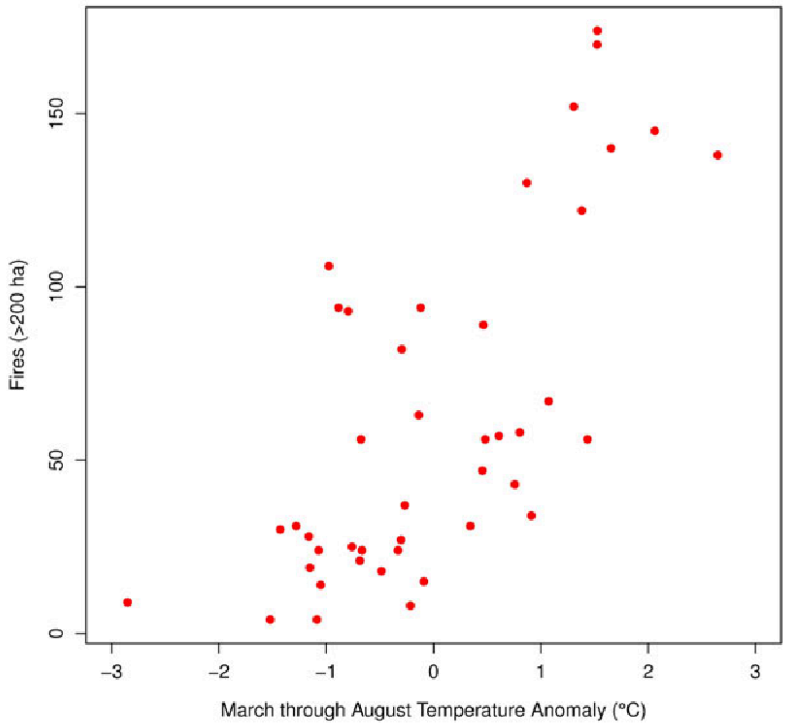
Note: all scatter plots are from MathIsFun.com

1. 	a. **x-axis:** Ocean temperature in degrees Celsius **y-axis:** hurricane wind speed
2. 	b. **x-axis:** Ocean temperature in degrees Celsius **y-axis:** sea level change in inches
3. 	c. **x-axis:** Ocean temperature in degrees Celsius **y-axis:** area of glaciers in square km
4. 	d. **x-axis:** Ocean temperature in degrees Celsius **y-axis:** number of phones owned in the United States

Think about it: How might numbers on each axis have helped you identify which representations went together? What about tables?

Appendix 7: How Does Temperature Change Affect Wildfires?

<u>Fig. 1: Wildfires and Temperature</u>



The chart to the left compares the temperature anomaly each year to the number of large fires that occurred in that year.

Graph sourced from Briefing: Climate and Wildfire in Western U.S. Forests, by Westerling, Brown, Schoennagel, Swetnam, Turner, and Veblen

1. What type of correlation does the scatter plot show? How do you know?

2. Explain how someone can tell if the correlation show is strong or weak, and if it is positive or negative.

3. An <u>outlier</u> is a point that differs significantly from the other observations in the scatter plot. Tristan claims that the far left point on the scatter plot is an outlier, while Naliyah says it is not. Who is correct? Why do their opinions differ?

4. A <u>cluster</u> in statistics consists of a set of observations that are grouped together. Identify any clusters in the scatter plot above, and explain why they might occur in this data.

5. Explain the concept of temperature anomaly seen on the x-axis. Why do climate scientists use this measure and what does it mean?

Appendix 8: Project Reflection

Stabilization Wedge #1:

1. What data did you use to investigate this wedge? How did you choose those variables?

2. Based on your scatter plot and line of best fit, are we currently on track to fulfill this stabilization wedge by 2050? Explain how you can tell, using statistical terms.

3. If your variable is not on track to fulfill the wedge by 2050, hypothesize one change that would need to be made to get there.
   If your variable is on track, determine if there is potential to go further--creating more than one wedge.

Stabilization Wedge #2:

1. What data did you use to investigate this wedge? How did you choose those variables?

2. Based on your scatter plot and line of best fit, are we currently on track to fulfill this stabilization wedge by 2050? Explain how you can tell, using statistical terms.

3. If your variable is not on track to fulfill the wedge by 2050, hypothesize one change that would need to be made to get there.
   If your variable is on track, determine if there is potential to go further--creating more than one wedge.

Appendix : Teacher Resources

1. For the data visualization gallery walk, teachers are encouraged to use charts found in these articles in The Guardian and Channel 4 News.
2. Yale Program on Climate Change's Six Americas Super Short Survey (SASSY!)
3. For additional practice on Bivariate Data using conceptual math and additional forms of questioning, use Open Up Resources, Grade 8, Unit 6.
4. Optional Extension: Keeping a Nature Journal, by Clare Walker Leslie.
5. NASA's Graphing Global Temperature Trends Activity.
6. Table on Fire Size (in Acres) compared to Year from the National Interagency Fire Center
7. More information on potential causes of climate change, as well as the scatter plot for Day Four, can be found here.
8. For Concept Two's Project, see Stabilization Wedges: A Concept & Game, by Princeton Environmental Institute.

Notes

1. Inspired by Thunberg, students worldwide began participating in the Global Climate Strikes to protest climate inaction, with participation peaking on September 20 with an estimated four million protestors.
Barclay, Eliza, and Brian Resnick, *How Big Was the Global Climate Strike? 4 Million People, Activists Estimate.*

2. Thunberg, Greta, *U.N. Climate Action Summit*.

3. Unless otherwise noted, content research is taken from Dessler, Andrew Emory, *Introduction to Modern Climate Change*, 1-142

4. For clarification, though the earth has experienced temperatures outside of today's averages, these temperatures occurred long before humans evolved, therefore encompassing climates that are not necessarily habitable for our species. These temperature variations also changed over the course of millions of years, instead of the hundreds hundreds of years changes are occurring over today. For more information, see Dessler, Andrew Emory, *Introduction to Modern Climate Change*, 112-124.

5. Hausfather, Zeke, *Carbon Brief*.

6. Socolow & Pacala, *Scientific American*, 50–57.

7. Socolow & Pacala, *Scientific American*, 52.

8. Socolow & Pacala, *Scientific American*, 54.

9. YPCC & Mason 4C, *Climate Change in the American Mind.*

10. Ballew, Leiserowitz, Roser-Renouf, Rosenthal, Kotcher, Marlon, Lyon, Goldberg, & Maibach, *Climate Change in the American Mind: Data, tools, and trends.*

11. Boaler, *What's Math Got to Do with It?* 139-166.

12. Boaler, *What's Math Got to Do with It?* 47.

13. Boaler, *What's Math Got to Do with It?* 57-77.

14. Boaler, *What's Math Got to Do with It?* 67.

15. For further information on Cornell Notes specifically, see:
"The Cornell Note-Taking System," Learning Strategies Center.

16. If digitally, the website allows educators to upload results directly to the website to compare with state and national results for SASSY.
"Six Americas Super Short Survey," Yale Program on Climate Change Communication.

17. Educators can choose visualizations from the linked articles in Teacher Resources.

18. Questions modified from OpenUp Resources Grade 8 Curriculum: Unit 6, Lesson 1.

19. Sobel, "Beyond Ecophobia."

20. For more information on the benefits of nature walks and nature journaling, as well as how to conduct both, see Leslie, Keeping a Nature Journal.

21. "Graphing Global Temperature Trends Activity," NASA.

22. *NASA's Earth Minute: Earth Has A Fever*. *YouTube*.

23. "Scatter Plots," https://www.mathsisfun.com/data/scatter-xy-plots.html.

24. Westerling, et. al. "Climate and Wildfire in Western US Forests."

25. Though the dataset is slightly different, students can create their own scatter plot from the table from the National Interagency Fire Center.

26. See: Components of Temperature Change in Haustein, Otto, Hausfather, and Jacobs, "Guest Post: Why Natural Cycles Only Play Small Role in Rate of Global Warming."

27. Hotinski, Roberta, "Stabilization Wedges: A Concept & Game."

28. "Math Curriculum," Open Up Resources.

29. Data collected from the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI) https://www.ncdc.noaa.gov/cag/county/time-series .

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