

# PReSto\*

## Teacher Guide

**\*Paleoclimate Reconstruction  
Storehouse of Proxy and Model  
Data:  
An Earth Science Curriculum**



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Wupatki Pueblo and National Monument near Flagstaff, Arizona. In the Hopi language, *wupatki* translates to “tall house.”

People have lived in the Southwest since time immemorial. They have built simple and intricate structures. These sites are sacred to the modern Indigenous peoples, especially to the Hopi, Navajo, Ute, and Apache peoples. Their livelihoods continue to be linked to the climate. When it is wet, they take advantage of the environment’s resources while dry spells create opportunities to either invent innovative ways to live or move on to other places.

At places like Wupatki National Monument, people took advantage of the pluvial during 1075-1121 CE and they moved on during the megadrought 1122-1299 CE. The pluvial brought a surplus of water to the region releasing nutrients into the soil for agriculture. However, by 1250 CE, the people moved to other places in search of better opportunities to live.

In first part of this curriculum, we will investigate how scientists decode the climate of the past and how the duration of wet and dry periods may impact how people live. Generally, more water in the environment, or pluvial, means better opportunities to extract resources, whereas a lack of water, or drought, means a stressful time to live and people can and continue to make choices based on better ways to live with their environment or to move to other places where those resources are available.

In the latter part of this curriculum, we will study the properties and behavior of how dust impacts our lives through scientific inquiry and respecting the cultural significance it holds for Indigenous communities, we can work towards mitigating its negative impacts while preserving the invaluable traditional knowledge that has guided sustainable living in harmony with the environment for generations.

1. [Ancient Dust: Unlocking the Secrets of the Past](#)
  2. [Wisdom of the Trees: Dendrochronology](#)
  3. [Wisdom of our Ancestors](#)
  4. [Dust in a Box](#)
  5. [Dust to Cloud](#)
  6. [Why do Dust Storms Happen?](#)
- [Suggested Rubrics](#)  
[Grades: 6-8](#)

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# 1. Ancient Dust: Unlocking the Secrets of the Past

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This lesson was adapted from the Lake Sediment Coring and Pollen Identification Activity provided by the Continental Scientific Drilling Facility, University of Minnesota.

<https://cse.umn.edu/csd>

## Arizona Earth and Space Science Standard 8.E1U1.6

Analyze and interpret data about the Earth's geological column to communicate relative ages of rock layers and fossils.

## Diné Content Standard

7th-8th Culture Standard

Concept 1: I will develop an understanding of Diné way of life.

Performance Objective 1: I will engage in activities that will increase my sense of self-worth.

## NGSS Performance Expectation

Students will use a physical model of a sediment core to determine patterns of proxy variations and infer environmental changes and use an interactive geographic map to determine patterns of warm and cold cycles.

## Instructor Set Up

### Materials

Spoons for mixing

Small plastic containers/Tupperware to hold mixtures (alternatively: glass jars)

Spices (mustard seeds, sesame seeds, celery seeds, poppy seeds, crushed dried leaves)

Paper towels

Clear plastic tubes with sealed ends/bowls/containers (alternatively: long glass or hard plastic vases may work)

Small spatula for smoothing the gel

Scotch tape

### Sodium Polyacrylate (sorbitol)

There are many brands available on the market and they all require a different ratio of water to powder to achieve a gel. Email Kat Cantner at [cantn001@umn.edu](mailto:cantn001@umn.edu) to confirm your material source before purchase.



## Spices

I find that full seeds are preferable to ground spice powder. Keep in mind that they must be small enough to fit in the straws and be collected during coring. I have had success with fennel seeds, but they are more challenging to use than smaller seeds. You can also use potting soil or other small, dried materials. The number of “pollen” types you want to create will depend on how many environmental indicators you want students to discern. The following materials have been found to be successful:

- Mustard seeds (yellow and/or brown)
- Celery seeds
- Poppy seeds
- Sesame seeds (white and/or black)
- Dill
- Red pepper flakes/black pepper (be careful when working with younger kids)
- Dried basil/parsley/marjoram (any crushed leaf)



## Pick Your Pollen

You may choose any combination of spices to represent your pollen. Below is an example relevant to the midwestern climate transition after the last glacial maximum. You can choose whatever is relevant for your students.

Pollen	Spice seed
Pine	Fennel or celery seed
Birch	Mustard seed
Grass	Poppy seed
Ragweed	Dill
Oak	White sesame seed
Charcoal	Black sesame seed

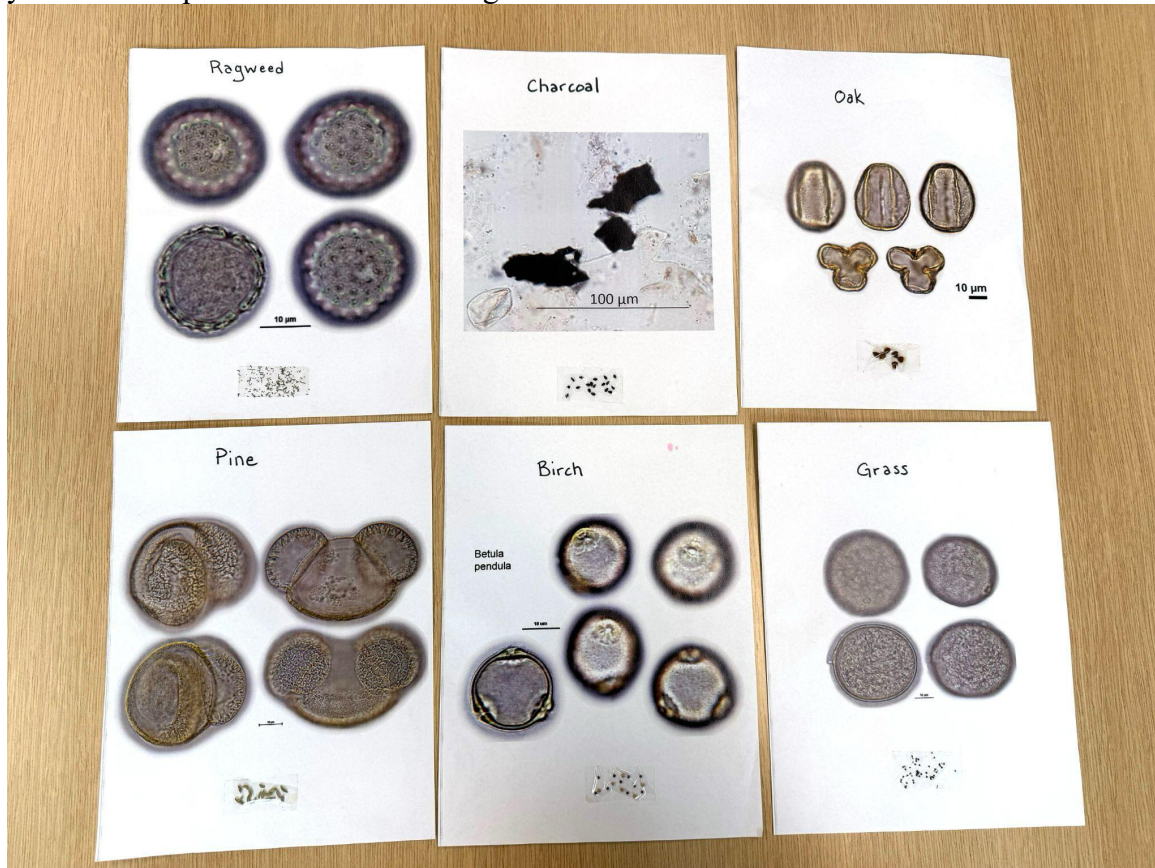
## Six Layers for Midwestern Holocene Climate Transition (top to bottom)

Geologic Time	Suggested food coloring
1. Recent record: Ragweed - often used as a marker for agriculture	light blue
2. Late Holocene: Pine and Birch	blue
3. Charcoal (date of 4,000 years ago)	red

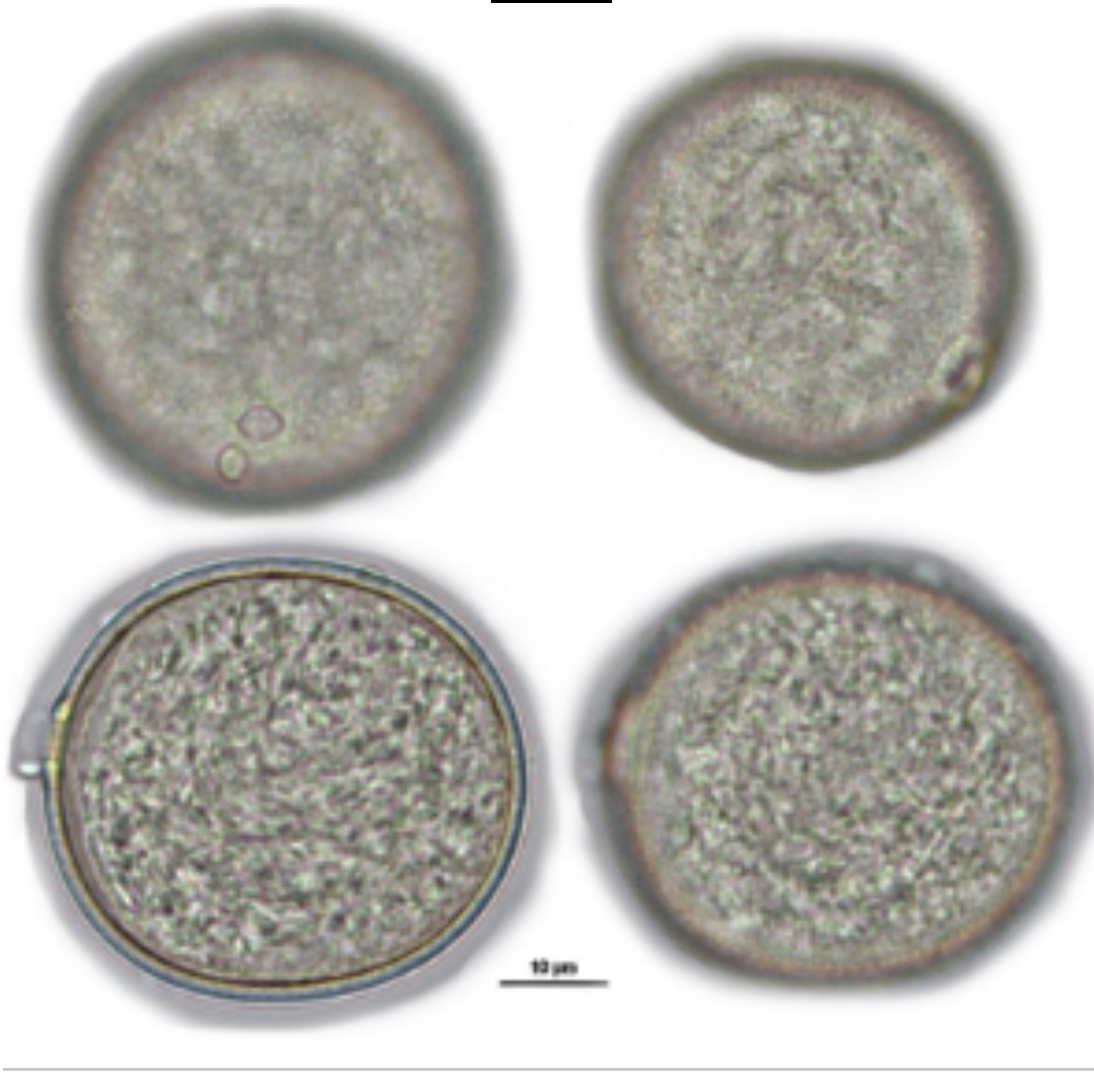
4. Mid-Holocene: Oak and Grass - overall transition to more non-arboreal pollen/fewer trees	red
5. Charcoal (date of 8,000 years ago)	light red
6. Early Holocene: Pine	Any (preference: clear)

### Print Pollen Images

Print the images of pollen under the microscope and use scotch tape to adhere a small amount of your chosen spice to the relevant image.



## Grass



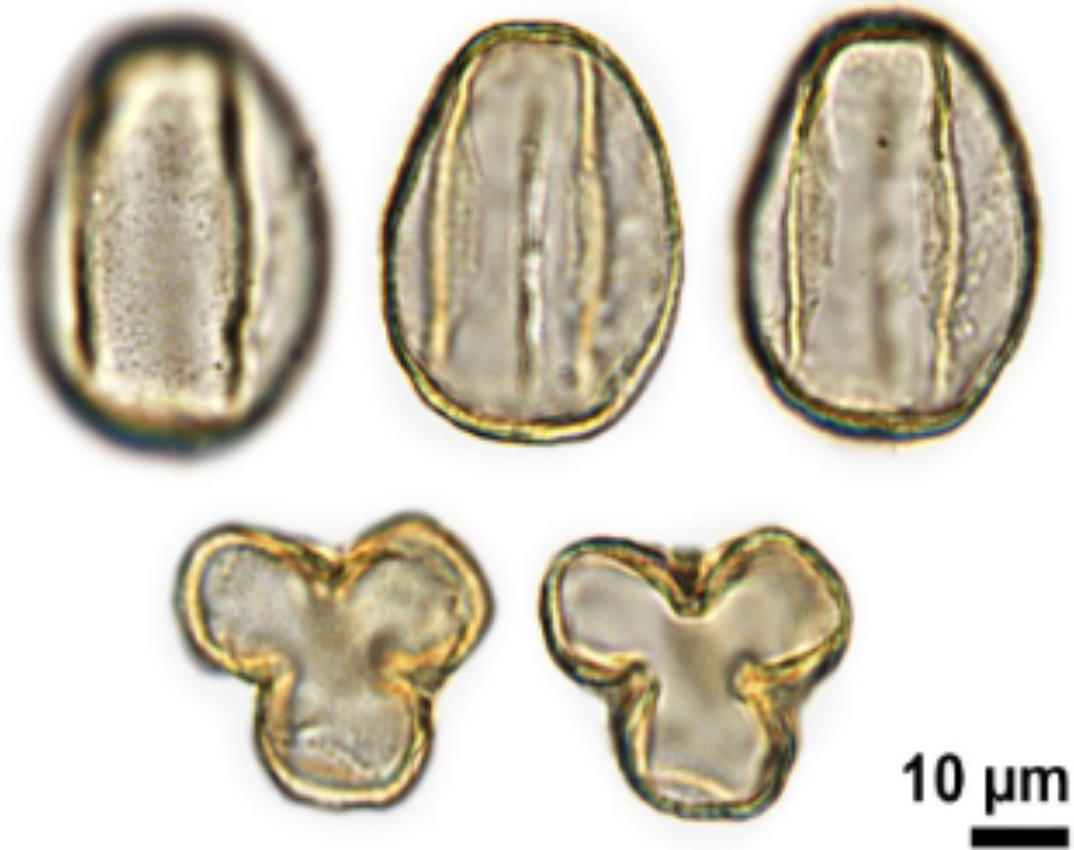
### **Fun Facts**

**Super Pollen Producer:** One ragweed plant can produce up to a **billion grains of pollen** in a season, contributing significantly to seasonal allergies in temperate climates.

**Temperature Tolerance:** Ragweed thrives in warm climates and can survive in temperatures up to **95°F (35°C)**, making it a robust species across various parts of North America.

**Resilient Native:** Although ragweed is native to North America, it's considered a nuisance because it spreads aggressively, especially in open, disturbed areas.

## Oak



### **Fun Facts**

**Mighty Acorns:** An oak tree can produce **millions of acorns** in its lifetime, providing food for wildlife in **temperate and subtropical regions** of North America.

**Temperature Adaptability:** Oaks can thrive in a wide range of temperatures, from the cool climates of the northern U.S. and Canada to the warmer climates of the southern U.S., tolerating temperatures from **-30°F to 100°F (-34°C to 38°C)**.

**Native Powerhouse:** Most oak species are native to North America, though some like the **English oak** have been introduced from Europe.

## Pine



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### **Fun Facts**

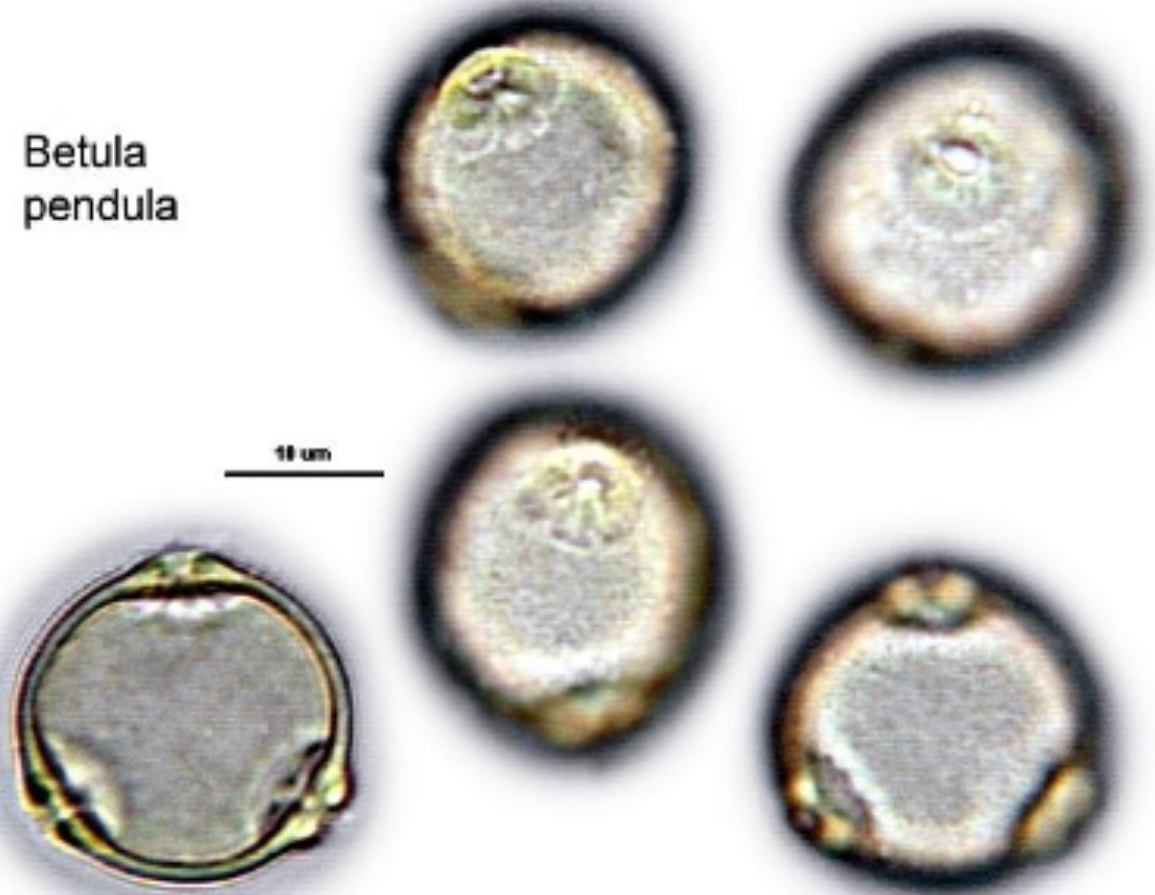
**Longest Living Tree:** Certain pines, like the Bristlecone Pine, can live for over 4,000 years and survive in extreme temperatures ranging from -40°F to 100°F (-40°C to 38°C).

**Cold Climate Survivor:** Many pine species thrive in cold climates and mountainous regions of North America, making them common in states like Colorado and Montana.

**Adaptable:** Pine species are typically native, but some species like the Scots Pine are exotic to North America, originating from Europe and Asia.

## Birch - Cold Climate

Betula  
pendula



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### Fun Facts

**Paper Bark:** The bark of the birch tree is **waterproof** and has been traditionally used by Indigenous peoples in **temperate climates**, particularly in areas with harsh winters like the northern U.S. and Canada.

**Cold Climate Lover:** Birch trees prefer **cool temperatures** and are often found in regions where the climate can drop as low as **-40°F (-40°C)**, making them a hallmark of northern forests.

**Rapid Growth:** Native to North America, birches grow quickly and are often used in reforestation projects in cooler climates.

## Ragweed - Warm Climate



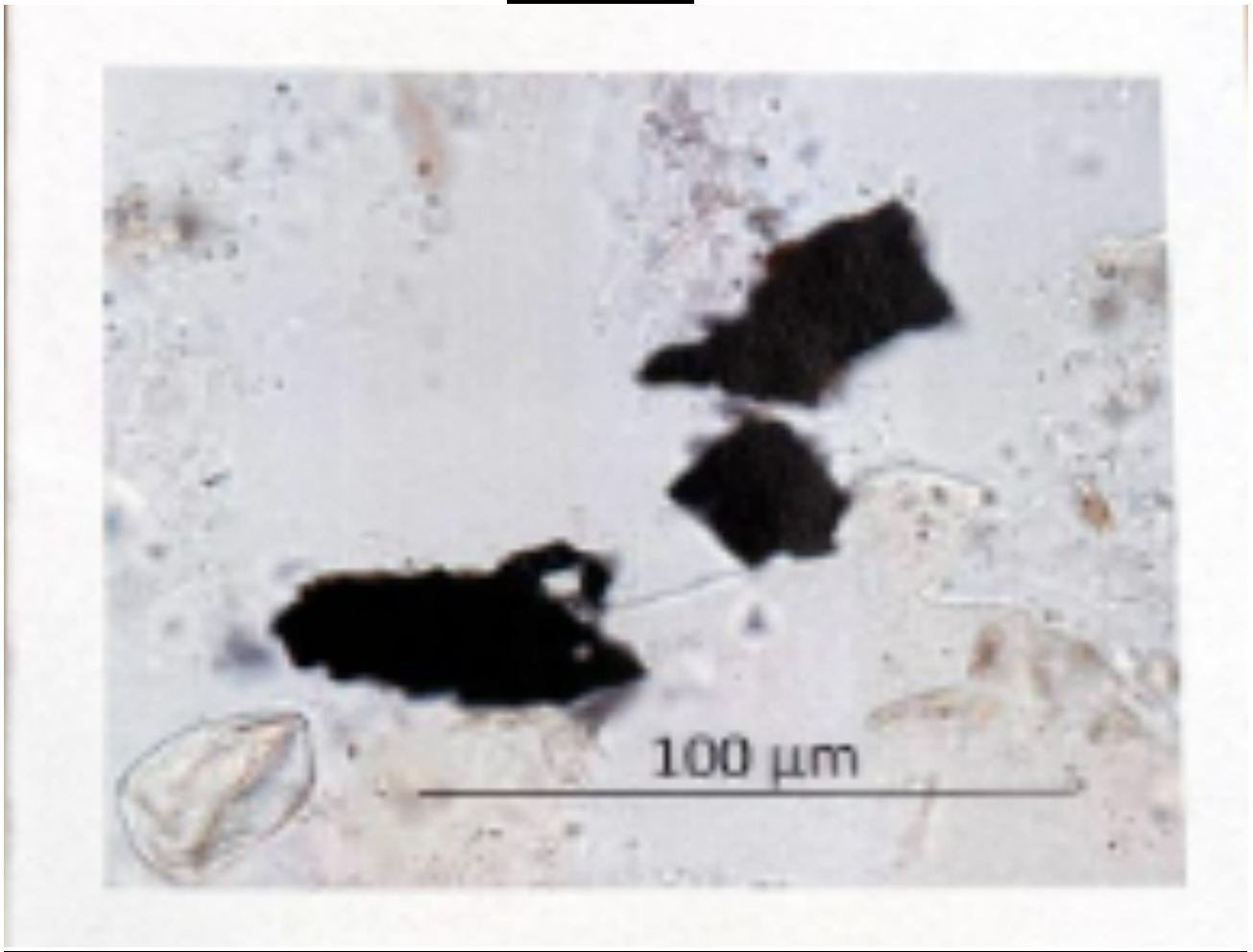
### **Fun Facts**

**Super Pollen Producer:** One ragweed plant can produce up to a billion grains of pollen in a season, contributing significantly to seasonal allergies in temperate climates.

**Temperature Tolerance:** Ragweed thrives in warm climates and can survive in temperatures up to 95°F (35°C), making it a robust species across various parts of North America.

**Resilient Native:** Although ragweed is native to North America, it's considered a nuisance because it spreads aggressively, especially in open, disturbed areas.

## Charcoal



Evidence of fire

## Selecting a Container

The container for your lake model must be watertight on the bottom. The two examples below are core liners with core caps taped onto the bottom with electrical tape. An average straw is 8 inches long. If your container is deeper than the straw, the students will not be able to sample the lowest layers. You may use a 2-liter bottle or juice container with the top cut off, however, remember that the wider your container, the more gel you will have to make to fill up the volume of your lake model. Alternatively, the students may create a longer corer by connecting two straws together end-to-end.



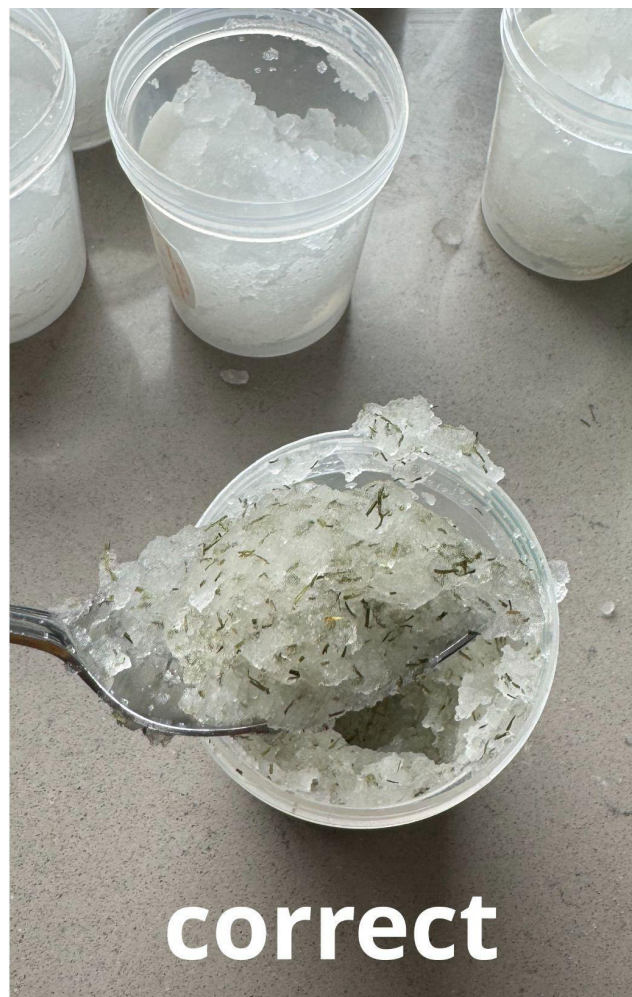
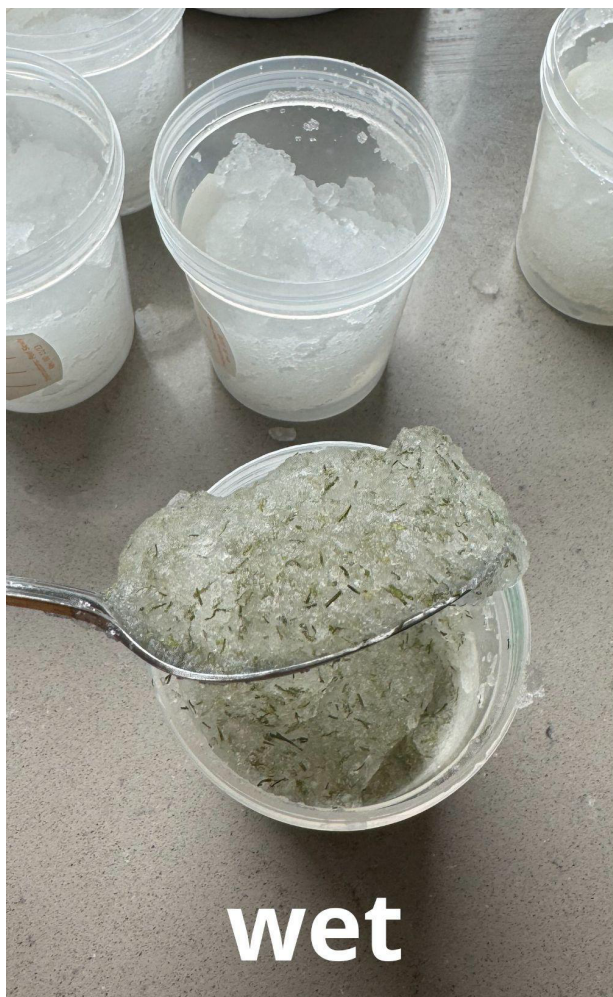
## Create the Lake Model

**\*\*Do ahead\*\*** The gel and lake model should last a week once made.

Create your lake sediment material by mixing sodium polyacrylate (Sorbitol) and water to create a gel. The amount of material you will need to create a substantial layer will depend on the container size you are using for your “lake”. For a polycarbonate tube, I use around 100 ml of water per layer.

1 teaspoon of Sorbitol = 100 mL of water

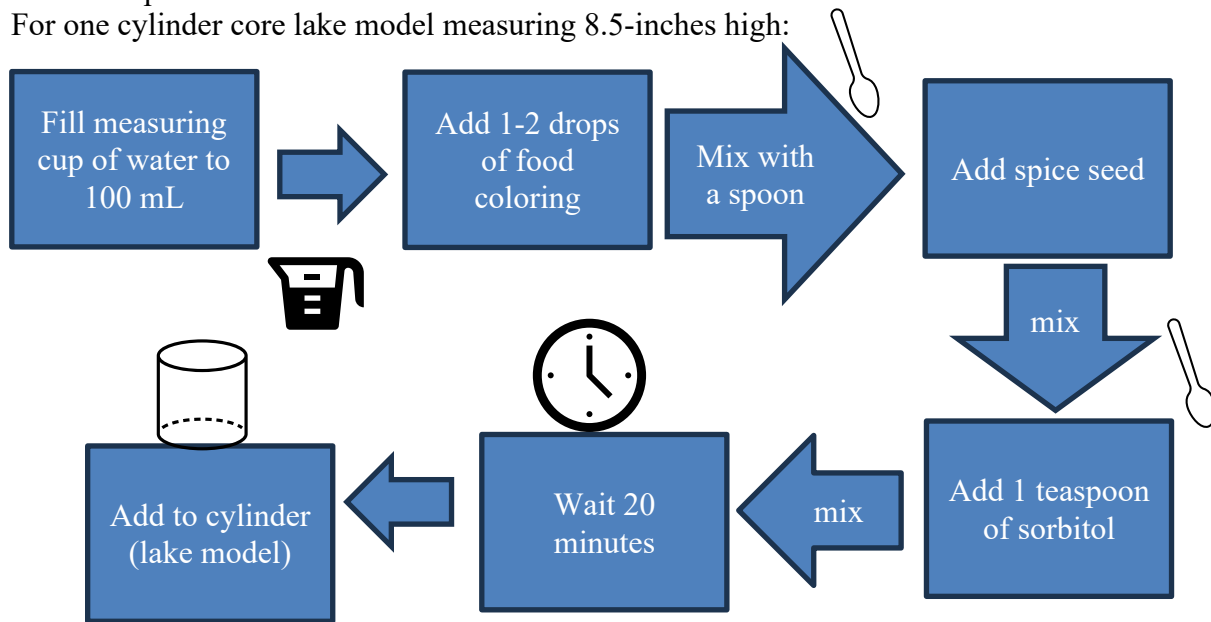
Mix your spice of choice into the gel and let sit for around 20 minutes. The polymer will react with the spice and become looser (wetter). After equilibrating, add more polymer powder to stiffen up the material. Repeat until you have enough “sediment” volume for at least 6 layers in your lake container.



Carefully spoon the mixtures into the lake container one at a time, smoothing after each addition to create even layers. Remember you are adding the OLDEST layer to the model first, so it will be at the bottom of your core.

Order of operations for best results:

For one cylinder core lake model measuring 8.5-inches high:



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## **2. Wisdom of the Trees**

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### **Arizona Earth and Space Science Standard 8.E1U3.7**

Obtain, evaluate, and communicate information about data and historical patterns to predict natural hazards and other geological events.

### **Diné Content Standard**

7th-8th Culture Standard

Concept 1: I will develop an understanding of Diné way of life.

Performance Objective 1: I will engage in activities that will increase my sense of self-worth.

### **NGSS Performance Expectation**

Students will use data from tree cookies and tree cores to determine patterns of drought and wet cycles.

### **Instructor Set Up**

#### **Materials**

Tree cookies (6-9 cm diameter)

Hand lens (magnifying glass)

Ruler (30 cm)

Mobile device with access to the world wide web

#### **Do Now**

Provide students with 5 minutes to complete this activity. Once they have completed the activity, discuss student responses without addressing correctness.

Distribute tree cookies (1-2 per group)

Go over how to count tree rings.

#### **Part I: Tree Cookie Analysis**

Students write down a response about the age of their tree cookie(s) and respond to the questions about patterns and about thickness of the rings.

#### **Part II: Tree Core Analysis**

Students analyze the tree core in their worksheet and determine the length using their rulers and the age. Students will find which rings are thinnest and infer drought years.

### **Discussion**

Students discuss the core's ring spacing and patterns, and potential events or environmental changes over the years.

## **Understanding from Nature – Traditional Knowledge**

In Navajo and Hopi cultures, traditional knowledge is vital in living among all beings in their ecosystem. The carbon cycle has and continues to be part of these cultures. Cycles in nature are an aspect of reciprocity, where one gives to receive, while to receive one gives.

Expand the Rs of traditional knowledge: reciprocity, respect, and responsibility.

Ask students to discuss about how might studying tree rings and their patterns connect to their cultural values of patience and respect for nature's teachings.

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### **3. Ancient Wisdom from Our Ancestors**

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#### **Arizona Earth and Space Science Standard 8.E1U3.7**

Obtain, evaluate, and communicate information about data and historical patterns to predict natural hazards and other geological events.

#### **Diné Content Standard**

7th-8th Culture Standard

Concept 1: I will develop an understanding of Diné way of life.

Performance Objective 1: I will engage in activities that will increase my sense of self-worth.

#### **NGSS Performance Expectation**

Students will use data from tree cores extracted from Navajo National Monument to determine patterns of drought and wet cycles and use an interactive geographic map to determine approximate ages of ancestral heritage sites.

#### **Instructor Set Up**

##### **Materials**

Tree cores of Navajo National Monument and modern Ponderosa Pines from the United States Geological Survey (and available below)

Hand lens (magnifying glass)

Ruler (30 cm)

Mobile device with access to the world wide web

##### **Do Now**

Provide students with 5 minutes to complete this activity.

- Hint students to look at the support structures of the adobe homes
- For the following questions, ask them to select whether they want to draw a 20-year-old tree cookie or a 30-year-old core.

Once they have completed the activity, discuss student responses without addressing correctness. Some students should notice the wooden beams supporting the adobe homes. Praise students when possible. Observe their drawings of their cookies and cores.

#### **Navajo National Monument – tree cores**

Replicas of tree cores are available here: <https://www.ltrr.arizona.edu/instruction/exercise-ptb.pdf>

These cores may be placed into boba/bubble straws.

Distribute materials, including rulers, replicas of tree cores from Navajo National Monument. Provide 5-10 minutes.

Discuss responses about Navajo National Monument. Responses will vary because each core will have different number of rings.

\*\*\*If there is time, students may work together to cross-date the 21 tree cores by looking for similar patterns between the samples.\*\*\*

Collect the cores.

## Modern tree cores

Distribute modern cores from the United States Geological Survey:



Credit: USGS.

You may cut these cores and mount them on boba/bubble straws prior to distribution.

Provide each group with one core sample. **Assume that these cores were made in 2020.**

## **Modern core**

Provide students with 5-10 minutes to complete this task.

Discuss their responses. Each group will have a different answer because of the nature of the different cores.

Collect the cores.

Distribute mobile devices (e.g., i-pads).

## **Virtual Dendrochronology**

Have students visit the Presto Project and load the interactive North American Drought Atlas (NADA): <https://paleopresto.org/visualizer.html?dataset=nada>

The NADA is a map and was created using about 1845 trees, consisting of Ponderosa Pines, Bristlecone Pines, Oaks, Junipers, and Douglas Fir. The NADA is used to estimate soil moisture and climate of the past.

Discuss the color bar prior to students engaging on this part of the activity.



The color bar is there to illustrate the two end members of soil moisture: dry and wet. Students mark an “x” on the color bar of their worksheet based upon the questions and their observations on the interactive map.

Go over the questions. Provide students with 5-10 minutes.

Discuss responses.

Collect the mobile devices.

## **Understanding from Nature – Traditional Knowledge**

In Navajo and Hopi cultures, trees are viewed as sacred beings to be respected. Traditional ecological knowledge values learning from observing nature closely over many years.

Discuss how this activity has impacted students’ cultures. How is knowing about the age of trees relate to where they come from?



*Dust* surrounds the lower regions of Dook'o'oostííd (“abalone shell mountain/the summit that never melts”) in Diné; Nuvatukya'ovi (“where the clouds live”) in Hopi.

Łeezh is the Diné word for dust, while the Hopi call this same word: Qö'angw.

In the arid regions of the Southwest, dust has long been recognized as an integral part of the natural environment by the Diné and Hopi peoples. Their traditional ecological knowledge teaches that dust is a sacred element, carrying the essence of the lands their ancestors inhabit. However, modern scientific understanding reveals that dust, comprised of tiny particles suspended in the air, can have detrimental effects on air quality, climate, and public health.

Dust particles, ranging from microscopic mineral fragments to biological materials like pollen and spores, can act as carriers for pollutants and allergens, contributing to respiratory issues and exacerbating conditions like asthma. Additionally, these airborne particles can absorb and scatter solar radiation, influencing the Earth's energy balance and potentially impacting climate patterns.

By studying the properties and behavior of dust through scientific inquiry and respecting the cultural significance it holds for Indigenous communities, we can work towards mitigating its negative impacts while preserving the invaluable traditional knowledge that has guided sustainable living in harmony with the environment for generations.

Students will work on activities developed at Northern Arizona and beyond to learn about what it's like to be a scientist and have an opportunity to relate their knowledge about the natural world. The duration of each activity is 50 minutes.

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## **4. Dust in a Box**

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### **Arizona State Standards:**

*Physical Science Standard 8.P4U2.5:* Develop a solution to increase efficiency when transferring energy from one source to another.

### **Objectives:**

*Students will be able to:*

- Use a physical model to represent how wind moves sediment (dust) and how dust can influence air quality.

### **Materials:**

- Sand/Silt/Clay (clay-sized particles are preferred)
- Water
- Plastic storage box (2)
- Hair drier
- Extension cord
- Glass gems (quantity: 10)
- Forks (3)
- Q-tips (10)
- Spray bottle
- Adhesive tape
- Student worksheet

Note: Parentheses indicates quantity

### **Introduction:**

Wind affects the landscape. If the wind is strong enough, it can move sediment.

### **Step-by-Step Activity:**

#### **I. Engage**

1. Have students write something about the wind and why it is important.
2. Ask students to indicate which of the pictures shows a model and to explain their justification.
3. Ask students about how dust moves.

#### **II. Explore**

Distribute the materials.

**Prior to the in-class procedure below, teacher should do the following:**

Box #1: Place about 5 cm deep of dry, sediment

Box #2: Place about 5 cm deep of wet, sediment

**Procedure:**

1. Box #1: Students are given or create a double stick tape and place on the other side of the box. Students use hair dryer above the sand.
2. Using the hairdryer (on the “cool” setting), blow lightly and increase wind. Remove the tape. Then, place your tape on the “Stick em’ up Collector” under the “Trial: Dry soil.”
3. Place adhesive tape or double-stick tape on the other side of the box.
4. Lightly spray Box #2 (with red dirt) so the soil absorbs the moisture. Using the hairdryer (on the “cool” setting), blow lightly and increase wind. Then, place the tape on the “Stick em’ up Collector” under the “Trial: Wet soil.”
5. Place adhesive tape or double-stick tape on the other side of the box.
6. Place and partially bury a few forks, Q-tips, and/or glass gems into the soil.
7. Using the hairdryer (on the “cool” setting), blow lightly and increase wind. Then, place your tape on the “Stick em’ up Collector” under the “Trial: Forks, qtips, +/- glass gems.”
8. Place adhesive tape or double-stick tape on the other side of the box.
9. Spray Box #2 (with red dirt) so the soil gets flooded.
10. Using the hairdryer (on the “cool” setting), blow lightly and increase wind. Then, place your tape on the “Stick em’ up Collector” under the “Trial: Flooded soil.”
11. Respond to the prompts below each circle that has dust.

**III. Explain**

Questions and further research. Note: Forks should model trees. However, if the forks generate more dust, then the environment has been “disturbed” (or tilled).

#5-6 Students respond to the questions independently

**IV. Elaborate**

#7 Students respond to the question independently

**V. Evaluate**

#8-9 Students draw a model about how dust is transported across the landscape

**Word Bank:**

Wind/Níyol (Diné)	model	gustnado
dust	process	haboob
aeolian	phenomenon	Níłtsá (Diné) and Qötö (Hopi)

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## 5. Dust to Cloud

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### Arizona State Standards:

*Physical Science Standard 8.P1U1.1:* Develop and use a model to demonstrate that atoms and molecules can be combined or rearranged in chemical reactions to form new compounds with the total number of each type of atom conserved. Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms. Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants. The total number of each type of atom is conserved, and thus the mass does not change.

### Objectives:

*Students will be able to:*

- Explore the role of dust in cloud formation and precipitation through hands-on activities.
- Develop models to understand the processes and energy transfers involved in the dust cycle.
- Evaluate the positive and negative impacts of dust on the environment and human health.
- Integrate traditional ecological knowledge (TEK) from the Diné (Navajo) and Hopi communities to understand the cultural and ecological significance of dust.

### Materials:

- Plastic bottle (1 or 2 liters)
- Plastic bottle caps with one that fits the needle of a pump valve
- Air pump
- Warm water (4 tablespoons)
- Can of hairspray
- Duct tape
- Optional: Funnel
- Optional: Isopropyl alcohol (Be careful, this is flammable)
- Optional: matches

### Introduction:

Although dust poses risks to air quality, safety, and public health, it may be responsible for mitigating climate warming and producing clouds for precipitation as cloud-condensation nuclei.

### Step-by-Step Activity:

#### I. Engage

1. Students explain how dust can be good, if at all.

## II. Explore

Student will be given the materials to engage with this activity.

**Note: Never use matches with hairspray or alcohol!**

## Procedure

Pour the 4 tablespoons of warm into the bottle. Close the bottle with a cap. Shake the bottle. Insert the needle into the cap. Pump the bottle with air. Ask your classmate to squeeze the bottle to make sure it is getting air. Once there is enough air inside the bottle, quickly release the cap.

## III. Explain

Students explain what happened.

Students perform the procedure again, but add a spray of hairspray into the bottle prior to pumping air.

Students describe what happened and what was different from previous trials.

Teachers perform the experiment with a match. **WARNING: Do not place a match in the bottle that previously had hairspray/alcohol because of fire hazard.**

Students describe what happened.

## IV. Elaborate

Students ask questions how dust is important in creating clouds and create a model.

## V. Evaluate

Students choose one of the prompts to respond

### Word Bank:

Cloud/k'os (Diné)	model	phenomenon
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## **6. Why do dust storms happen?**

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### **Arizona State Standards:**

*Earth and Space Standard 8.E1U3.7:* Obtain, evaluate, and communicate information about data and historical patterns to predict natural hazards and other geological events.

### **Objectives:**

*Students will be able to:*

- Identify the factors that contribute to the formation of dust storms.
- Analyze and compare data from different locations to understand the conditions that lead to dust storms.
- Explore the impacts of dust storms and climate change through traditional ecological knowledge (TEK) from the Diné and Hopi communities.
- Use a model to represent how wind moves sediment (dust) and how dust can influence air quality.

### **Materials:**

- Student worksheet "Why do dust storms happen?"
- Video clip: ["Our Beautiful Planet: Dust Rising"](#) (National Science Teaching Association)
- Video clip: ["A Record of Change: Science and Elder Observations on the Navajo Nation"](#) (United States Geological Survey and the Navajo Nation)
- Maps, photos, and data related to wind patterns and dust storms in different locations

### **Lesson Procedure:**

#### **1. Engage (10 minutes):**

- Display the image of a dust storm from the United States Geological Survey (USGS) and have students write a 2-3 sentence description.
- Watch the video clip "Our Beautiful Planet: Dust Rising" (from the beginning to 2:00).
- Discuss what creates dust storms based on the video.

#### **2. Explore (30 minutes):**

- Divide students into small groups and provide them with data and information about Phoenix, Arizona, and Birmingham, Alabama.
- Have students analyze the similarities and differences between the two cities in terms of latitude, proximity to the ocean, and the occurrence of dust storms.
- Guide students in examining wind maps and photos of the two locations to identify potential factors contributing to dust storms.
- Have students generate hypotheses about the ingredients required for a dust storm.

### **3. Explain (20 minutes):**

- Watch the video clip "A Record of Change: Science and Elder Observations on the Navajo Nation" (from the beginning to 07:00).
- Facilitate a class discussion about the local people's observations and perspectives on climate change, their vulnerability, and the impacts of climate change on the Navajo Nation.
- Introduce the concept of traditional ecological knowledge (TEK) and its importance in understanding environmental phenomena.

### **Suggested Local Traditional Ecological Knowledge (TEK):**

- Discuss how TEK can provide valuable insights into the impacts of dust storms and climate change on local ecosystems, traditional practices, and human health.
- Explore the potential connections between TEK and conventional scientific knowledge in understanding and addressing environmental challenges.

### **4. Extend (20 minutes):**

- Divide students into small groups and assign each group a story or case study about a specific dust storm event (e.g., Dust Storm in Northeastern Arizona, Dust Storm in Phoenix, Saharan Dust Storm, etc.).
- Have students read and analyze their assigned story, focusing on the factors contributing to the dust storm and its impacts.
- Facilitate a class discussion where each group shares their findings and insights.
- Encourage students to reflect on the potential positive and negative impacts of dust storms and the role of dust in various ecosystems.

### **Assessment:**

- Formative assessment through observation of student engagement, participation, and responses during class discussions and group activities.
- Evaluation of students' completed worksheets, focusing on their analyses, hypotheses, and understanding of the factors contributing to dust storms.
- Summative assessment through a written assignment or project where students synthesize their learning and apply it to a real-world scenario or case study.

### **Word Bank:**

Gustnado → Haboob (Arabic)

→ Níłtsá (Diné)

→ Qötö (Hopi)

## Suggested Rubrics

These are suggested rubrics. The complete PReSto curriculum is worth up to 100 points, each lesson being worth up to 20 points each.

### 1. [Ancient Dust: Unlocking the Secrets of the Past](#)

Criteria	Excellent (4 points)	Proficient (3 points)	Developing (2 points)	Emerging (1 point)
Analysis of Sediment Core (SEP: Analyzing and Interpreting Data)	Thoroughly analyzes the sediment core, accurately identifying all layers, measuring their thickness, and describing patterns in detail. Makes insightful connections between layers and environmental changes.	Analyzes the sediment core, identifying most layers, measuring their thickness, and describing some patterns. Makes reasonable connections between layers and environmental changes.	Partially analyzes the sediment core, identifying some layers and measuring their thickness. Makes limited connections between layers and environmental changes.	Minimally analyzes the sediment core, with few accurate layer identifications or measurements. Makes no clear connections between layers and environmental changes.
Interpretation of Relative Ages (CCC: Patterns)	Accurately interprets the relative ages of all layers in the core, providing a clear and logical explanation for the ordering. Demonstrates a strong understanding of the principle of superposition.	Interprets the relative ages of most layers in the core, providing a reasonable explanation for the ordering. Shows a good understanding of the principle of superposition.	Interprets the relative ages of some layers in the core, with partial explanation for the ordering. Shows basic understanding of the principle of superposition.	Minimally interprets the relative ages of layers, with little or no explanation. Shows limited understanding of the principle of superposition.
Identification of Plant Communities and Climate Changes	Accurately identifies all pollen types and makes well-reasoned inferences about past plant communities and climate changes. Provides detailed evidence to support conclusions.	Identifies most pollen types and makes reasonable inferences about past plant communities and climate changes. Provides some evidence to support conclusions.	Identifies some pollen types and makes basic inferences about past plant communities or climate changes. Provides limited evidence to support conclusions.	Identifies few pollen types and makes minimal inferences about past plant communities or climate changes. Provides little or no evidence to support conclusions.
Group work (Comparative Analysis)	Thoroughly compares core samples with classmates, identifying multiple similarities and differences. Draws insightful conclusions about what scientists can learn from lake sediment cores.	Compares core samples with classmates, identifying some similarities and differences. Draws reasonable conclusions about what scientists can learn from lake sediment cores.	Partially compares core samples with classmates, identifying few similarities or differences. Draws limited conclusions about what scientists can learn from lake sediment cores.	Minimally compares core samples with classmates. Draws no clear conclusions about what scientists can learn from lake sediment cores.
Integration of Traditional Knowledge	Makes thoughtful and relevant connections between the sediment core analysis and Indigenous stories of emergence or other cultural worldviews. Provides a detailed explanation or illustration.	Makes reasonable connections between the sediment core analysis and Indigenous stories of emergence or other cultural worldviews. Provides a clear explanation or illustration.	Makes basic connections between the sediment core analysis and Indigenous stories of emergence or other cultural worldviews. Provides a simple explanation or illustration.	Makes minimal or no connections between the sediment core analysis and Indigenous stories of emergence or other cultural worldviews. Provides little or no explanation or illustration.

## 2. [Wisdom of the Trees](#)

Criteria	Excellent (4 points)	Proficient (3 points)	Developing (2 points)	Emerging (1 point)
Understanding of age determination from tree ring patterns	Demonstrates comprehensive understanding of how tree rings infer the age of a tree	Shows good understanding with minor misconceptions	Displays basic understanding with some significant gaps	Exhibits minimal understanding of how trees may be used as clocks
SEP: Obtain, evaluate, and communicate information	Able to evaluate information provided, synthesize, and communicate information provided	Develops a good understanding of obtaining and communicating information with minor inaccuracies	Able to determine the age of a tree	Attempts to determine the age of a trees but consists of major flaws
CCC: Patterns	Provides synthesis of patterns to infer age and drought and wet cycles.	Explains age determination based on the patterns of tree rings with good accuracy, but lacks understanding in drought and wet cycles	Attempts to explain patterns found in the tree rings with some misconceptions	Minimally addresses how tree rings can be used to determine age
Incorporation of Traditional Knowledge	Seamlessly integrates relevant traditional knowledge into the tree ring patterns	Incorporates traditional knowledge with good connections to tree ring patterns	Includes some traditional knowledge with tenuous links to cycles; may mention reciprocity.	Mentions traditional knowledge but fails to connect it to the cycles
Cultural values of patience and respect	Integrates patience and respect into the how nature teaches us	Incorporates either patience or respect in understanding nature and traditional knowledge	Includes patience or respect, but may not accurately explain or illustrate the links to traditional knowledge	Fails to respond to the question

## 3. [Ancient Wisdom](#)

Criteria	Excellent (4 points)	Proficient (3 points)	Developing (2 points)	Emerging (1 point)
Understanding of age determination from tree ring patterns	Accurately draws a cookie or core with correct number of rings and interprets meaning (e.g., wide/narrow rings)	Draws tree rings with mostly correct number and general understanding	Attempts to draw rings but shows confusion about age or meaning	Random or inaccurate drawing with no clear link to age
Understanding of age determination from tree ring patterns	Accurately draws a cookie or core with correct number of rings and interprets meaning (e.g., wide/narrow rings)	Draws tree rings with mostly correct number and general understanding	Attempts to draw rings but shows confusion about age or meaning	Random or inaccurate drawing with no clear link to age
Virtual Dendrochronology using PReSto	Uses the NADA map effectively, marks all years correctly, and interprets climatic patterns (wet/dry periods) accurately	Completes most map tasks with some understanding of patterns	Attempts to mark map but has difficulty interpreting patterns or years	Marks map incorrectly or incompletely and lacks interpretation
Navajo National Monument and Modern Core Analysis	Answers all questions with accurate age, identification of thin rings, and strong environmental inferences	Mostly accurate answers with good effort to explain environmental signals	Partial responses with limited interpretation of data	Fails to respond or responses lack relevance to age or environment
SEP: Science & Engineering Practice – Obtain, evaluate, and	Synthesizes all tree ring and map data clearly, drawing well-supported conclusions	Understands and communicates tree ring patterns with minor errors	Attempts to explain patterns but with limited	Makes unsupported or incorrect

communicate information			depth or accuracy	statements about tree rings
CCC: Crosscutting Concept – Patterns and Traditional Knowledge	Clearly explains how tree ring patterns reflect environmental cycles and connects this to traditional ecological knowledge	Makes good connections between patterns and traditional views of trees	Mentions either patterns or traditional knowledge, but links are weak	Provides disconnected or unclear statements with minimal connection to the lesson

#### 4. [Dust in a Box](#)

Criteria	Excellent (4 points)	Proficient (3 points)	Developing (2 points)	Emerging (1 point)
Understanding of Energy Transfer Concepts	Demonstrates comprehensive understanding of energy transfer in wind-driven dust movement	Shows good understanding with minor misconceptions	Displays basic understanding with some significant gaps	Exhibits minimal understanding of energy transfer concepts
SEP: Developing and Using Models	Creates a sophisticated model that clearly demonstrates energy transfer in dust movement	Develops a good model with minor inaccuracies in representing energy transfer	Creates a basic model that partially represents energy transfer	Attempts to create a model but with major flaws in representing energy transfer
CCC: Energy and Matter: Flows, Cycles, and Conservation	Provides a detailed explanation of energy flow and conservation in dust movement, considering multiple factors	Explains energy flow and conservation with good accuracy, considering some key factors	Attempts to explain energy flow and conservation with some misconceptions	Minimally addresses energy flow and conservation with significant errors
Solution Development	Develops a highly innovative and well-reasoned solution to increase efficiency in dust movement	Proposes a good solution with clear reasoning	Offers a basic solution with some logical gaps	Presents a vague or poorly developed solution
Incorporation of Traditional Knowledge	Seamlessly integrates relevant traditional knowledge into the solution	Incorporates traditional knowledge with good connections to the solution	Includes some traditional knowledge with tenuous links to the solution	Mentions traditional knowledge but fails to connect it to the solution

#### 5. [Dust to Cloud](#)

Criteria	Excellent (4)	Proficient (3)	Developing (2)	Emerging (1)
Model Development (NGSS SEP: Developing and using models) (4 points)	Student creates a detailed and accurate model demonstrating how dust particles contribute to cloud formation, clearly showing the rearrangement of atoms and molecules. (4 pts)	Student creates a model showing how dust particles contribute to cloud formation, with some representation of atomic/molecular rearrangement. (3 pts)	Student creates a basic model of cloud formation with dust particles, but atomic/molecular rearrangement is unclear or incomplete. (2 pts)	Student attempts to create a model, but it lacks clear representation of dust particles or atomic/molecular rearrangement. (1 pt)
Conservation of Matter (AZ Standard 8.P1U1.1) (5 points)	Student clearly explains and demonstrates in their responses that the total number of atoms is conserved during the cloud formation process, despite the rearrangement of molecules. (5 pts)	Student explains that atoms are conserved during cloud formation but may have minor gaps in demonstrating this concept. (4 pts)	Student shows some understanding of atom conservation, but explanation lacks detail or contains misconceptions. (2-3 pts)	Student shows little to no understanding of atom conservation in the cloud formation process. (1 pt)

Cause and Effect Analysis (NGSS CCC: Cause and effect) (4 points)	Student provides a detailed analysis of how the addition of dust particles (hairspray or match) affects cloud formation, clearly linking cause (dust particles) to effect (cloud formation). (4 pts)	Student explains the relationship between dust particles and cloud formation, showing a general understanding of cause and effect. (3 pts)	Student identifies that dust particles affect cloud formation, but the cause-effect relationship is not clearly articulated. (2 pts)	Student struggles to connect dust particles to cloud formation or does not address cause and effect. (1 pt)
Integration of Local Traditional Knowledge (3 points)	Student incorporates relevant local traditional knowledge about weather patterns or cloud formation, making clear connections to the scientific concepts learned. (3 pts)	Student mentions local traditional knowledge related to weather or clouds, with some attempt to connect it to scientific concepts. (2 pts)	Student references local traditional knowledge, but connections to scientific concepts are weak or unclear. (1 pt)	Student does not incorporate local traditional knowledge or makes irrelevant connections. (0 pts)
Scientific Communication (4 points)	Student's written responses and drawings are clear, detailed, and demonstrate a thorough understanding of the concepts. Scientific terminology is used accurately and appropriately. (4 pts)	Student's responses and drawings are mostly clear and show a good understanding of the concepts. Some scientific terminology is used correctly. (3 pts)	Student's responses and drawings show basic understanding, with some unclear explanations. Limited use of scientific terminology. (2 pts)	Student's responses and drawings are unclear or incomplete, demonstrating minimal understanding. Scientific terminology is absent or used incorrectly. (1 pt)

## 6. [Why do Dust Storms Happen?](#)

Criteria	Excellent (4)	Proficient (3)	Developing (2)	Emerging (1)
Understanding of Dust Storm Formation (Standard 8.E1U3.7)	Thoroughly explains the causes of dust storms, including both wind and dry conditions. Clearly identifies the two main ingredients required for dust storms.	Explains the main causes of dust storms and identifies the two main ingredients but may lack some detail.	Explains some causes of dust storms but may miss key points. Identifies only one ingredient required for dust storms.	Limited or incorrect explanation of dust storm causes. Does not identify the required ingredients for dust storms.
Data Analysis and Interpretation (SEP)	Accurately analyzes and interprets data from wind maps and city comparisons to draw valid, detailed conclusions about dust storm occurrence.	Analyzes data from wind maps and city comparisons with minor errors, drawing mostly valid conclusions about dust storm occurrence.	Attempts to analyze data from wind maps and city comparisons but makes some errors in interpretation or conclusions.	Limited or incorrect analysis of data. Fails to draw meaningful conclusions about dust storm occurrence.
Patterns (CCC)	Clearly identifies and thoroughly explains patterns in dust storm occurrence, relating them to multiple geographical and climate factors.	Identifies and explains some patterns in dust storm occurrence, relating them to key geographical and climate factors.	Identifies basic patterns in dust storm occurrence but may not fully explain their relationship to geographical and climate factors.	Does not identify meaningful patterns in dust storm occurrence or fails to relate them to relevant factors.
Integration of Traditional Knowledge	Thoroughly explains the difference between traditional knowledge and conventional science. Provides	Explains key differences between traditional knowledge and conventional science. Provides at	Explains some differences between traditional knowledge and conventional science. Provides at	Limited or no explanation of traditional knowledge. Does not provide

	multiple, detailed examples of climate change impacts observed by local people.	least two examples of climate change impacts observed by local people.	least one example of climate change impacts observed by local people.	examples of climate change impacts observed by local people.
Prediction of Natural Hazards	Uses historical patterns and data to make well-reasoned, detailed predictions about where and when dust storms might occur.	Uses historical patterns and data to make reasonable predictions about dust storm occurrence, with some supporting evidence.	Makes basic predictions about dust storm occurrence based on data, but predictions may lack detail or full justification.	Does not make predictions about dust storm occurrence or makes predictions without supporting evidence.

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## Additional Standards

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This curriculum may be used throughout middle and high school levels and in all 50 states, however the focus of these hands-on activities is geared towards eight graders learning science in Arizona.

According to the Arizona Science Standards, the three dimensions of the Next Generation Science Standards are expressed using the following **disciplinary core ideas** and **crosscutting concepts**:

- *In sixth grade, students apply their understanding of the **cycling of matter, energy flow, and scale**, as it relates to **molecules, geosphere, the solar system, and ecosystems**.*
- *In seventh grade, students will investigate the relationship between forces and the changes in motion, **how energy transfer impacts geologic and atmospheric processes, and the structure and function of cells**.*
- *In eighth grade, students will describe how **cause-and-effect** interact with **stability and change** to influence the **natural world**.*

These are additional Arizona Science Standards that may be used for the appropriate grade levels:

- Sixth grade: Focus on **Patterns; Scale, Proportion, and Quantity; Systems and System Models; Energy and Matter**
  - 6.L2U1.14: **Construct a model** that shows the cycling of matter and flow of energy in **ecosystems**.
- Seventh grade: Focus on **Patterns; Cause and Effect; Structure and Function**
  - 7.E1U1.5: **Construct a model** that shows the cycling of matter and flow of energy in the **atmosphere, hydrosphere, and geosphere**.
- Eighth grade: Focus on **Cause and Effect; Energy and Matter; Stability and Change**
  - 8.P4U1.3: **Construct an explanation** on how energy can be transferred from one energy store to another.
  - 8.E1U1.6: **Analyze and interpret data** about the **Earth's geological column to communicate relative ages of rock layers and fossils**.
  - 8.E1U3.7: **Obtain, evaluate, and communicate** information about data and historical **patterns** to **predict natural hazards and other geological events**.
- High school:
  - Essential HS.E1U1.11: **Analyze and interpret data** to determine how energy from the Sun affects weather **patterns** and climate.

- Plus HS+E.E1U1.1: **Construct an explanation** based on evidence for how the **Sun's energy transfers between Earth's systems**.
  - Plus HS+E.E1U1.2: **Develop and use models** to describe **how variations in the flow of energy into and out of Earth's systems result in changes in climate**.
  - Plus HS+E.E1U1.3: **Analyze** geoscience **data** and the results from global climate models to make evidence-based **predictions of current rate and scale of global or regional climate changes**.
- Essential HS.E1U1.12: **Develop and use models** of the Earth that explains the role of energy and matter in **Earth's constantly changing internal and external systems (geosphere, hydrosphere, atmosphere, biosphere)**.
  - Plus HS+E.E1U1.4: **Analyze and interpret** geoscience data to make the claim that **dynamic interactions with Earth's surface can create feedbacks that cause changes to other Earth systems**.
  - Plus HS+E.E1U1.5: **Obtain, evaluate, and communicate information** on the **effect of water on Earth's materials, surface processes, and groundwater systems**.
- Essential HS.E1U1.13: **Evaluate** explanations and theories about the **role of energy and matter in geologic changes over time**.
  - Plus HS+E.E1U1.8: **Develop and use models** to illustrate how **Earth's internal and surface processes operate over time to form, modify, and recycle continental and ocean floor features**.
- Essential HS.E1U3.14: **Engage in argument from evidence** about the **availability of natural resources, occurrence of natural hazards, changes in climate, and human activity and how they influence each other**.
  - Plus HS+E.E1U3.9: **Construct an explanation, based on evidence**, for how the **availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity**.
  - Plus HS+E.E1U3.10: **Ask questions, define problems, and evaluate** a solution to a complex problem, based on **prioritized criteria and tradeoffs, that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts**.
  - Plus HS+E.E1U3.11: **Develop and use a quantitative model** to illustrate the **relationship among Earth systems and the degree to which those relationships are being modified due to human activity**.

## Tribal Standards

There are 574 federally acknowledged tribes and each of these sovereign nations may have additional education standards to serve their local communities.

The Navajo Nation has its own Diné Cultural Standards and they are based on living in harmony (hózhó) with the natural world. The natural law states that people are part of Mother Earth and Father Sky and must treat each with love and respect and protect them for future generations. Traditionally, the Diné are a matriarchal society, where women determine descent and inheritance.

According to the Navajo Nation Department of Education, there are performance objectives (PO):

- Grades 4-6: “I will organize and keep track of my personal belongings.”
  - PO 2-3: Formulate questions to interview an elder or grandparents and report how they take care of their personal items. Report by showing peers with photos.
  - PO 2-2: Create and use a KWL (know, want to learn, learned) chart to infer what the cause and effects would be if one does not take care of personal items at school and home. Then research to find facts to prove inferences were correct/incorrect Share with peers and lower grades.
  - PO 2-1: Develop a matrix that show their personal items and tell how they are taken care of. In small groups, explain to group members how to take care of personal items.
- Grades 7-8: “I will show responsibility by knowing the stories related to my belongings.”
  - PO 2-8: Identify, collect, and display cultural items that are considered personal belongings. Interview elders and research reasons why and how to care for those items. Explain and show presentation to peers, schools, family, and community.
  - PO 2-7: List personal items and belongings that have meaning and significance. Explain how and why each is valuable. Share with peers
  - PO 2-6: Interview a professional organizer and create a presentation to show and demonstrate information to peers, school, and family on how to organize personal, home, and school items.
  - PO 2-5: Brainstorm and list how to organize and take care of personal belongings at home (different types of clothing in drawers, closet, containers, dishes, utensils, pots/pans, linens, tools, etc.). Create a matrix to show how each is organized.
- Grades 9-12: “I will care for my belongings and teach accordingly.”:
  - PO 2-11: Make observations, infer, and explain what happens when belongings are taken care of. Create a media presentation to teach peers, and schools about how to take care of belongings and explain and show their role as a responsible teen.
  - PO 2-10: Develop a matrix to organize interpretation and share with classmates.
  - PO 2-9: List items and belongings that have meaning and significance. Explain how each is valuable. Explain, show, and demonstrate how each item or belonging is cared for.

Navajo Nation Department of Education Diné Content Standards: <https://oscad.navajo-nsn.gov/Resources/Dine-Content-Standards>

Navajo Nation-NOAA Meteorological Poster:  
<https://www.weather.gov/images/fgz/NavajoPoster.jpg>

The Hopi Tribe is in the process of developing its own standards.

Please research your local community’s education standards for further guidance.

New Mexico State Science Standards: STEM Ready!  
 Middle School Recommended Discipline Course Map  
<https://web.ped.nm.gov/wp-content/uploads/2025/01/Middle-School-Discipline-Specific-Course-Map-3-19.pdf>

The New Mexico middle school course map recommends teaching Earth & Space Science in the 6<sup>th</sup> grade.

## References

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### **Activities:**

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### **Traditional Knowledge:**

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Semken, S. C., & Morgan, F. (1997). Navajo pedagogy and Earth systems. *Journal of Geoscience Education*, 45(2), 109-112.

This guide is available at <https://bit.ly/4mKFWjU>



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## Supply List (Materials)

<b>Activity</b>	<b>Items</b>	<b>Quantity</b>
Ancient Pollen	Vase	4
Ancient Pollen	Spoons	1
Ancient Pollen	Straws (Boba-style)	1
Ancient Pollen	Measuring cups	4
Ancient Pollen	Sorbitol (Sodium polyacrylate)	1
Ancient Pollen	Spatula	1
Ancient Pollen	Spice bottle	7
Ancient Pollen	Mustard seeds (yellow and/or brown)	1
Ancient Pollen	Celery seeds	1
Ancient Pollen	Poppy seeds	1
Ancient Pollen	Sesame seeds (white and/or black)	1
Ancient Pollen	Dill	1
Ancient Pollen	Red pepper flakes/black pepper (be careful when working with younger kids)	1
Ancient Pollen	Dried basil/parsley/marjoram (any crushed leaf)	1
Ancient Pollen	Scotch tape	1
Wisdom of the Trees	Tree cookies (6-9 cm diameter)	5
Wisdom of the Trees	Hand lens	5
Wisdom of the Trees/Ancient Wise Ancestors	Ruler	4
Dust in a Box	Q-tips	2 packages
Dust in a Box	Double-stick tape	3
Dust in a Box	Hair Drier	1
Dust in a Box	Spray bottle	1
Dust in a Box	Plastic boxes	4
Dust to Cloud	Air pump	4
Dust to Cloud	1-L plastic bottle	5
Dust to Cloud	Needles for pump	4

Items not included: food coloring for the Ancient Pollen activity and clear boba straws for the Ancient Wise Ancestors activity; more hair driers for Dust in a Box; more air pumps for Dust to Cloud.